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Aerobic Work Capacity

IN

Men and Women

WITH SPECIAL REFERENCE TO

Age

BY

IRMA ÅSTRAND

STOCKHOLM 1960

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ACTA PHYSIOLOGICA SCANDINAVICA

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AEROBIC WORK CAPACITY IN MEN AND WOMEN WITH SPECIAL REFERENCE TO AGE

BY

IRMA ÅSTRAND

STOCKHOLM 1960

STOCKHOLM 1960. KUNGL. BOKTRYCKERIET P. A. NORSTEDT & SÖNER

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PREFACE

This study was made during a period of about 6 years. It was, to a great extent, a team work and many persons contributed to its accomplishment in different ways. The subjects' willingness and interest in participating in the experiments, which sometimes were quite strenuous, were greatly appreciated.

Generous contributions were given by Sveriges Riksidrottsförbund (The Swedish Sports Federation), Personaladministrativa Rådet (The Swedish Council for Personnel Administration), Svenska Bryggeriindustriarbetareförbundet (Swedish Brewery Workers' Union), Bryggeriarbetsgivareförbundet (Employers' Association of the Swedish Breweries) and the Pennsylvania Department of Health Grant.

To all those persons and institutions who facilitated this work I wish to express my sincere thanks.

It is the hope of the author that the results of this investigation will contribute to improve our knowledge of man at work, especially with regard to age.

Stockholm, February 1960

IRMA ÅSTRAND

INTRODUCTION

Despite increased mechanization in industry there are still many occupations which demand moderately severe or severe muscular work, and consequently considerable oxygen uptake capacity ("physical fitness") of the worker. This is also true for countries which are at the top of the list with regard to high living standard and industrial mechanization. For this reason it is of great practical interest to determine how the capacity for oxygen uptake varies in the two sexes and in different ages. This is one way of estimating the available manpower in different age groups. It is also of practical interest for other reasons, for example when investigating heart diseases, and for estimating an older individual's capacity to partake in activities outside the home, for example in sports, and gardening.

The oxygen uptake capacity (aerobic work capacity) is also of interest theoretically, especially with regard to the biological influence of ageing on various functions. Boys and girls up to adult age were investigated in this respect by P.-O. Åstrand, 1952, and adults in various age groups by Robinson, 1938. The latter material, however, consisted only of men and was small, especially above 50 years of age.

The object of this investigation is to contribute to a further analysis of the aerobic work capacity for females and males in different ages. The material consists of physically active individuals. A material of this kind is more homogeneous and ought to give more unequivocal information about the effect of ageing *per se* on the aerobic work capacity than a material chosen at random. In such a material many other variables exist which can contribute to blur the picture of biological ageing.

The contents may be divided into the following main topics:

1) An attempt to outline the capacity for oxygen uptake and related functions for a certain group of men and women up to 65 years of age.

2) Investigation and evaluation of submaximal work tests with which one can estimate the capacity for oxygen uptake.

3) Investigation of how well the measured capacity for oxygen uptake correlates with the ability to perform submaximal work during a relatively long period.

A part of the material to be discussed here has been published in the following articles:

I) RYHMING, I.[1], A modified Harvard step test for the evaluation of physical fitness. *Arbeitsphysiologie* 1953. *15.* 235—250.

II) ÅSTRAND, P.-O. and I. RYHMING, A nomogram for calculation of aerobic capacity (physical fitness) from pulse rate during submaximal work. *J. appl. Physiol.* 1954. *7.* 218—221.

III) ÅSTRAND, I., The physical work capacity of workers 50—64 years old. *Acta physiol. scand.* 1958 a. *42.* 73—86.

IV) ÅSTRAND, I., Clinical and physiological studies of manual workers 50—64 years old at rest and during work. *Acta med. scand.* 1958 b. *162.* 155—164.

V) ÅSTRAND, P.-O. and I. ÅSTRAND, Heart rate during muscular work in man exposed to prolonged hypoxia. *J. appl. Physiol.* 1958. *13.* 75—80.

VI) ÅSTRAND, I., P.-O. ÅSTRAND and K. RODAHL, Maximal heart rate during work in older men. *J. appl. Physiol.* 1959. *14.* 562—566.

The rest of the material is presented in parts I—VII. The author has tried to present each individual part as an independent unit.

I. Capacity for oxygen uptake and related functions during cycling in women 20—65 years old.

II. Mechanical efficiency of young and old people at low and high work loads during cycling.

III. Vital capacity and 1.0-second's expiratory capacity in women 20—65 years old.

IV. Electrocardiograms at rest and during and after work in women 20—65 years old.

V. A method for prediction of aerobic work capacity for females and males of different ages.

VI. A pilot study of work on a treadmill in women 20—65 years old.

VII. Physiological effects of prolonged muscular work for one hour and for one day.

[1] Married name ÅSTRAND.

PART I

CAPACITY FOR OXYGEN UPTAKE AND RELATED FUNCTIONS DURING CYCLING IN WOMEN 20—65 YEARS OLD

Introduction

Very little is known about the capacity for oxygen uptake and related functions in women. Certainly even less is known about the variations in these functions with age. The following experiments have been carried out in an attempt to contribute to an elucidation of these problems.

Material

Forty-four female subjects were investigated. Eight were 20—29 years old, 12 were 30—39, 8 were 40—49 and 16 were 50—65 years old. Forty-one were housewives and 6 of these had another job outside the home. Three were unmarried (laboratory assistant, maid and student). The number of children varied from 1 to 4 for 35 subjects, the total being 61. All of them regularly took part in organized calisthenics for housewives; twenty-three twice a week or more and twenty-one once a week for half an hour each time. Most of them had participated in some sort of organized exercise since they left school. The volunteers were chosen at random by their instructor to take part in the investigation.

The series of observations began with a careful clinical examination. For these results see part IV. No one took part who had any detectable sickness or abnormality that could influence the ability to perform heavy exercise. Three were excluded from the original group of 47 because of severe hypertension (discovered at the examination), chronic valvular heart disease and varicose veins with ulceration. Regarding the subjects' age, body weight and height, see Table I: I.

Methods

For the *statistical methods* used in this and the other parts see FISHER (1946).

The work experiments were performed on a KROGH bicycle ergometer and the pedal frequency was set at 50/min by a metronome. In order to obtain the exact pedal frequency it was registered continuously. The experiments followed the lines described by I. ÅSTRAND, P.-O. ÅSTRAND and RODAHL (1959). The first load used was 300 kpm/min[1]. The subjects were investigated on 3—7 different days.

[1] kpm = kilopond meter; 1 kp is the force acting on the mass of 1 kg at normal acceleration of gravity.

TABLE I: I. *Body weight and height, FVC (fast vital capacity) and 1.0-sec EC (1.0-second's expiratory capacity) in per cent of FVC in the different age groups of female subjects. The two lung volumes were determined in a sitting position (for methods see part III, p. 33). Mean age is denoted within parentheses. Mean values ± standard errors of the means and S. D. are given*

age group, yr.	n of subj.	weight kg	height cm	FVC l BTPS	1.0-sec EC per cent
20—29	8	56.2 ± 2.15	166 ± 1.9	3.79 ± 0.16	84.3 ± 2.1
(25.0)		6.1	5.3	0.44	5.9
30—39	12	57.5 ± 1.93	165 ± 1.5	3.79 ± 0.15	82.9 ± 1.5
(34.7)		6.7	5.1	0.50	5.2
40—49	8	61.9 ± 1.51	164 ± 2.0	3.58 ± 0.18	80.3 ± 1.8
(43.9)		4.3	5.7	0.49	5.1
50—65	16	65.4 ± 2.21	160 ± 0.7	3.24 ± 0.10	79.3 ± 1.4
(55.6)		8.8	2.8	0.41	5.4

The criteria for evaluating whether or not the subject's maximal level for oxygen uptake was attained were essentially the same as those used by P.-O. ÅSTRAND (1952, p. 23) and by I. ÅSTRAND, P.-O. ÅSTRAND and RODAHL (1959). These criteria are: 1) that oxygen uptake does not increase despite a rising work load, but reaches a level and/or 2) that blood lactate concentration is high, 90—100 mg per 100 ml, after work of at least 4 min duration.

For the older subjects in this material these criteria could not always be followed, since on the average they did not reach the same high blood lactate concentration as the younger. ROBINSON experienced the same phenomenon in 1938. This implies less objectively established strain for the older subjects. However, the whole procedure was the same for both young and old. According to the author's impression the physical strain of the older was at least as great as that of the younger subjects. The experiments were made under the personal supervision of the author.

When P.-O. ÅSTRAND compared children to adults he met with the same difficulties (1952, p. 23). To be able to further analyse the problem he divided his 14—18-year-old subjects into two groups: "one where no further increase in oxygen uptake ($\dot{V}o_2$[1]) was seen at the highest working intensities ($\dot{V}o_2$ "levelling off"), and one where $\dot{V}o_2$ steadily increased with increasing speed ($\dot{V}o_2$ not "levelling off")". No difference in $\dot{V}o_2$ per kg body weight was found between the two groups. For the males the lactic acid concentration was highest in the first group (103 compared to 92) and for the females it was highest in the second group (94 compared to 116 mg per 100 ml). If the same

[1] This and the following symbols and abbreviations are taken from a report by PAPPENHEIMER (1950).

TABLE I: II. *The division of the subjects regarding age and body size into two groups: 1) where the oxygen uptake levels off by increasing work loads and 2) where it does not. Mean maximal oxygen uptake and blood lactate concentration ± standard error of the mean and S. D. for the two groups of female subjects are given*

age groups, yr.	$\dot{V}O_2$ "levelling off"					$\dot{V}O_2$ not "levelling off"				
	n of subj.	weight kg	height cm	$\dot{V}O_2$, l STPD	lactate conc. mg per 100 ml	n of subj.	weight kg	height cm	$\dot{V}O_2$, l STPD	lactate conc. mg per 100 ml
20–29	3					5				
30–39	7	59.2	162	2.00 ± 0.07	93 ± 4.1	5	62.4	163	2.04 ± 0.06	86 ± 4.0
40–49	2			0.3	18	6			0.3	20
50–65	8					8				
	20					24				

basis for group division is used for the present material, 20 will belong to the first "levelling off" group and 24 to the second group. As can be seen from Table I: II, no special selection occurred regarding age or body size to the two groups. There is no difference between the two groups, neither in the maximal $\dot{V}o_2$ (2.00 and 2.04 l respectively) nor in the lactate concentration (93 and 86 mg per 100 ml). If the subjects in the second group had not forced themselves to the same degree as those in the first, the lactate concentration should have been lower.

Heart rate was counted each minute during work with the help of a visoscope connected to an electrocardiograph. (The recorded electrocardiograms are discussed in part IV.) The exact time was taken for 30 beats. The heart rates given in the tables are means of all values obtained during the time for air collection. Thus, the values obtained from the ECGs recorded during the collection of expired air are included. If the heart rate increased throughout the cycling the highest value was given.

The subject started to breathe through a valve after about 4 min of work, and 1/2 min later the expired air was collected in two consecutive DOUGLAS bags. The number of respirations in each bag was registered electrically with the help of a tambour, and *respiratory frequency* (f) and *tidal air* (V_T) were calculated. The time for the air collection was measured exactly by a stopwatch. At the lower work loads the collection time for each bag was about 2 min, and at the higher about 1/2 min. At the maximal work load the period before the air collection sometimes had to be shorter, since the subject could not always continue cycling for 5—6 min. In such cases 3—5 consecutive bags

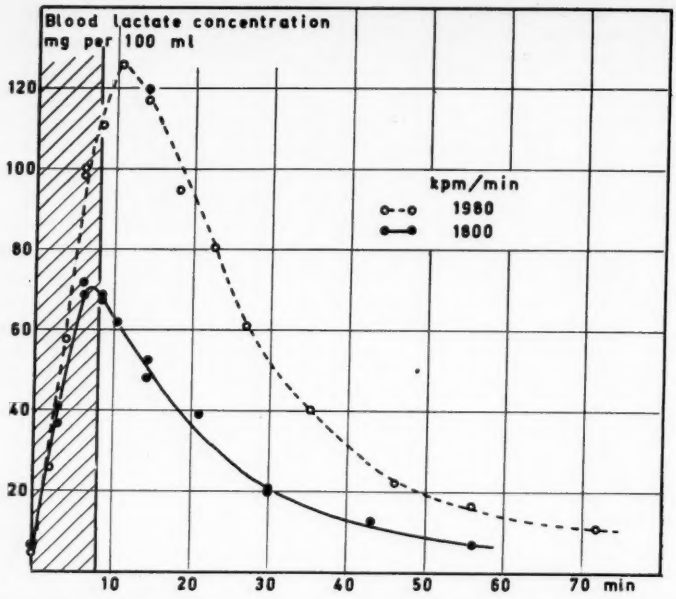

Fig. I: 1. Blood lactate concentration during and after work of 8 min duration (striped column) in the same male subject.

were sometimes taken.[1] The air volume was immediately measured in a balanced spirometer (150 l) in which it could be measured with an accuracy of 0.1 l. The air was analysed for O_2 and CO_2 according to the HALDANE technique. *Oxygen uptake* per minute ($\dot{V}o_2$) was calculated. The values given for f, V_T, $\dot{V}o_2$ and for *pulmonary ventilation* per minute ($\dot{V}_E$) were calculated on the basis of individual mean values of at least two determinations. However, the maximal values represent the highest values of each individual if the two measurements with regard to $\dot{V}o_2$ differed more than 0.08 l/min, representing 1 per cent confidence limit in the agreement between the values. The error of the method for determination of oxygen uptake at submaximal work was calculated from the differences between two consecutive determinations of 40 different subjects chosen at random. The average difference was 0.008 $\pm$ 0.007 l/min. The error for a single determination was 0.029 l/min or 1.7 per cent of the mean of the first determination.

[1] A study of the importance of the length of the work time at various work loads when measuring maximal oxygen uptake has been more systematically carried out by P.-O. ÅSTRAND (personal communication, to be published). Mainly, the results show that with higher work loads the increase in $\dot{V}o_2$ is faster and maximal $\dot{V}o_2$ is attained in a shorter time.

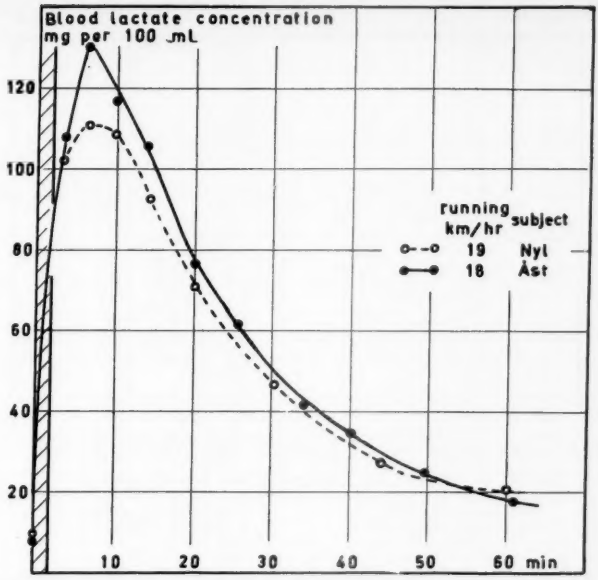

Fig. I: 2. Blood lactate concentration after severe work of 2 min duration (striped column) in two subjects, one female and one male.

Blood samples for determination of the *lactic acid concentration* were taken from a thoroughly dried fingertip (the hand was warmed in water of about 40° C for about 1 min) about 1 and 4 min after the work stopped. At the highest work loads a third sample was often taken after about 6—8 min. The reason why the blood was collected at that time is that the highest values for lactate concentration at a heavy load are first reached between 1 and 10 min after the work is stopped, see Fig. I: 1 and I: 2. During submaximal loads of short duration (5—10 min) the lactate concentration does not decrease significantly before the end of the work. Compare BANG (1936) and P.-O. ÅSTRAND (1952, p. 22). The lactic acid was analysed according to a modification (STRÖM, 1949) of the original colorimetric method described by BARKER and SUMMERSON (1941). Standard solutions of three different concentrations were used. The blood volume was varied so that the concentration in the specimen never exceeded 70 mg per 100 ml in order to avoid the critical point where the correlation between concentration and extinction plotted on a semi-logarithmic paper no longer forms a straight line. A double determination of each sample was always made and the mean value used. The peak lactate concentrations for the different work loads are given in the tables. The error of the method was given by I. ÅSTRAND (1958 a), and was, for a single determi-

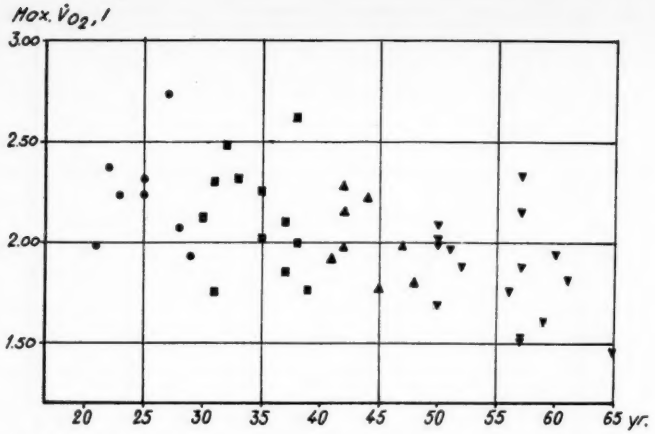

Fig. I: 3. Individual maximal oxygen uptake ($\dot{V}O_2$; STPD) in relation to age (n = 44). ● 20—29; ■ 30—39; ▲ 40—49 and ▼ 50—65 years, female subjects.

TABLE I: III. *Mean values ± standard errors of the means and S. D. are given for oxygen uptake, blood lactate concentration and heart rate during maximal work for the different age groups of female subjects*

age groups, yr.	n of subj.	$\dot{V}O_2$, l STPD	$\dot{V}O_2$, ml/kg STPD	lactate conc. mg per 100 ml		heart rate
				maximal	corresp. to max. $\dot{V}O_2$	
20—29	8	2.23 ± 0.09	39.9 ± 1.66	121 ± 6.8	107 ± 6.5	187 ± 3.4
		0.26	4.7	19	19	10
30—39	12	2.13 ± 0.08	37.3 ± 1.51	97 ± 4.6	95 ± 3.5	185 ± 2.0
		0.28	5.2	16	12	7
40—49	8	2.01 ± 0.07	32.5 ± 0.96	86 ± 6.8	86 ± 6.8	178 ± 3.0
		0.19	2.7	19	19	8
50—65	16	1.85 ± 0.06	28.4 ± 0.68	78 ± 3.3	78 ± 3.3	170 ± 2.1
		0.25	2.7	13	13	9
20—25	44	2.90 ± 0.04	48.4 ± 0.5	—	104 ± 2.8	198 ± 1.5
P.-O. Å-D (1952)		0.25	3.2	—	18	10

nation calculated from 30 duplicate determinations for concentrations between 0—25 mg per 100 ml, ± 1.26 (7.9 per cent), 25—50 mg per 100 ml, ± 1.66 (4.5 per cent) and over 50 mg per 100 ml, ± 1.92 mg per 100 ml (3.1 per cent).

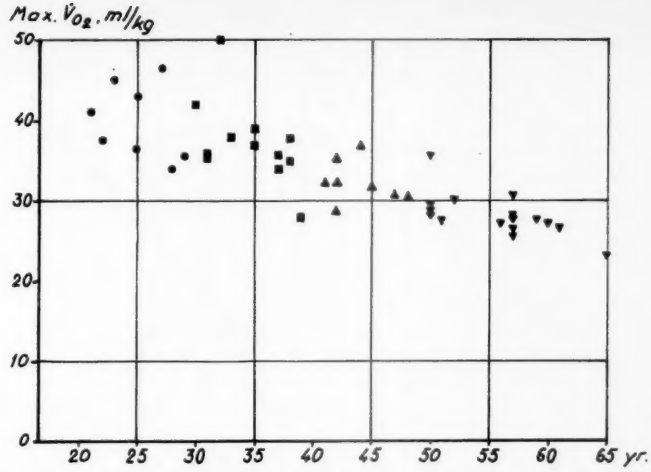

Fig. I: 4. Individual maximal oxygen uptake ($\dot{V}_{O_2}$; STPD) per kg weight in relation to age (n = 44). For the symbols see Fig. I: 3.

TABLE I: IV. *Mean values ± standard errors of the means and S. D. are given for female subjects for pulmonary and estimated alveolar ventilation, the ratio of pulmonary and alveolar ventilation to oxygen uptake, respiratory frequency, tidal air and tidal air in per cent of forced vital capacity. The values for $\dot{V}_E$ and $\dot{V}_A$ were obtained in the same experiments as the maximal $\dot{V}_{O_2}$ was measured. The values for f and V_T are the maximal values actually recorded*

age groups, yr.	n of subj.	$\dot{V}_E$, l BTPS	$\dot{V}_E/\dot{V}_{O_2}$ l	$\dot{V}_A$, l BTPS	$\dot{V}_A/\dot{V}_{O_2}$ l	f	V_T l BTPS	V_T/FVC × 100 per cent
20–29	8	76.2 ± 5.71	34.1 ± 2.10	65.2 ± 4.59	29.2 ± 1.61	38.8 ± 2.8	2.0 ± 0.09	54 ± 3.9
		16.2	6.0	13.0	4.6	7.8	0.3	11
30–39	12	75.0 ± 4.40	35.2 ± 1.64	63.2 ± 3.86	29.6 ∓ 1.34	36.9 ± 2.3	2.1 ± 0.11	55 ± 1.7
		15.3	5.7	13.4	4.7	8.1	0.4	6
40–49	8	64.4 ± 4.89	31.8 ± 1.64	53.3 ± 4.14	26.3 ± 1.39	37.0 ± 3.4	1.9 ± 0.07	52 ± 2.0
		13.8	4.7	11.7	3.9	9.5	0.2	6
50–65	16	60.5 ± 1.26	33.1 ± 1.00	50.3 ± 1.18	27.5 ± 0.84	33.7 ± 1.4	1.9 ± 0.08	58 ± 2.1
		5.1	4.0	4.7	3.4	5.6	0.3	9
20–25	44	89.8 ± 1.6	32.3 ± 0.5	—	—	46.0 ± 1.0	—	—
P.-O. Å-D (1952)		10.3	2.8	—	—	6.0	—	—

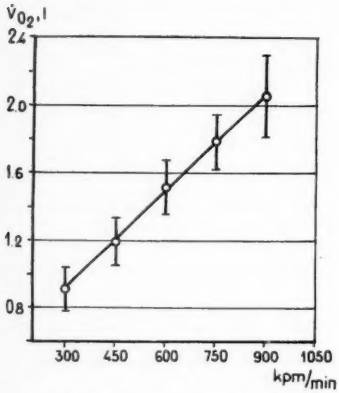

Fig. I: 5. Oxygen uptake ($\dot{V}O_2$; STPD) in relation to work load for all subjects. 300, 450, 600: n = 44; 750: n = 25; 900: n = 17. $\overline{\underline{\phi}}$ = mean value $\pm$ 2 $\times$ $\times$ S.D., female subjects.

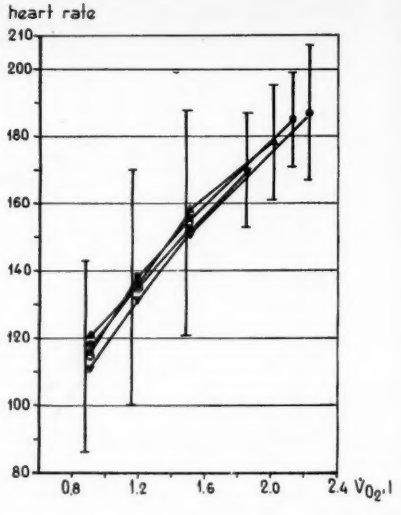

Fig. I: 6. Heart rate in relation to oxygen uptake ($\dot{V}O_2$; STPD) for the different age groups (n = 44). ● 20—29; ■ 30—39; ▲ 40—49 and ▼ 50—65 years, female subjects. $\overline{\underline{\phi}}$, $\overline{\underline{\bullet}}$ = mean value $\pm$ 2 $\times$ S.D., unfilled dots represent all subjects, filled dots the different age groups.

Results

The maximal values for $\dot{V}o_2$, blood lactic acid concentration and heart rate are summarized as mean values for the different age groups in Table I: III.

The maximal $\dot{V}o_2$ is highest in the 20—29-year-old group, or 2.23 l. It gradually decreases to 1.85 (with 17 per cent) for the 50—65-year-old group. When calculated as $\dot{V}o_2$ per kg body weight the decrease is somewhat higher, or 29 per cent. It decreases from 39.9 to 28.4 ml/kg $\times$ min. The individual data for the total $\dot{V}o_2$ and $\dot{V}o_2$ in relation to weight are given in Fig. I: 3 and I: 4. The various maximal values concerning pulmonary ventilation are presented in Table I: IV. The same methods for studying these functions were used by P.-O. Åstrand (1952). His values on 44 physically well-trained 20—25-year-old students of physical education are therefore included in the tables.

All the submaximal mean values of $\dot{V}o_2$, heart rate, $\dot{V}_E$ and blood lactate concentration for the different age groups are given in Table I: V. Values for $\dot{V}o_2$ at submaximal work loads are plotted in Fig. I: 5. From the figure it is obvious that there is a rectilinear relationship between the two variables. Since there were only small variations in $\dot{V}o_2$ for the various ages, the mean

TABLE I: V. *Submaximal mean values ± standard errors of the means and S. D. are given for oxygen intake, heart rate, pulmonary ventilation and blood lactate concentration in the different age groups of female subjects*

age group, yr.	n of subj.	$\dot{V}O_2$, l STPD	heart rate	$\dot{V}E$, l BTPS	lact. conc. mg/100 ml
300 kpm/min[1]					
20–29	8	0.86 ± 0.02	118 ± 5.4	20.7 ± 0.56	18 ± 1.7
		0.06	15	1.6	5
30–39	12	0.90 ± 0.02	116 ± 4.3	23.3 ± 1.20	18 ± 1.3
		0.06	15	4.2	5
40–49	8	0.90 ± 0.02	121 ± 4.8	22.0 ± 1.30	16 ± 1.1
		0.04	14	3.7	3
50–65	16	0.95 ± 0.02	111 ± 3.3	24.1 ± 0.84	19 ± 1.4
		0.08	13	3.4	6
450 kpm/min[1]					
20–29	8	1.16 ± 0.02	135 ± 6.8	29.4 ± 1.95	30 ± 4.4
		0.06	19	5.5	13
30–39	12	1.18 ± 0.03	138 ± 5.5	34.2 ± 2.93	24 ± 2.3
		0.08	19	10.2	8
40–49	8	1.18 ± 0.01	136 ± 4.8	29.2 ± 0.97	24 ± 1.5
		0.03	14	2.8	5
50–65	16	1.23 ± 0.02	131 ± 4.8	33.0 ± 1.20	33 ± 2.9
		0.08	19	4.7	11
600 kpm/min[1]					
20–29	8	1.48 ± 0.02	152 ± 7.0	38.0 ± 2.32	44 ± 7.9
		0.06	20	6.6	22
30–39	12	1.49 ± 0.02	155 ± 4.9	40.9 ± 1.92	36 ± 2.9
		0.07	17	6.7	10
40–49	8	1.50 ± 0.03	158 ± 3.8	36.9 ± 1.51	36 ± 3.7
		0.08	11	4.3	11
50–65	[2] 16	1.54 ± 0.02	151 ± 4.4	43.5 ± 1.63	45 ± 4.7
		0.09	18	6.5	19
750 kpm/min[1, 3]					
20–29	4	1.73 ± 0.03	160 ± 12.0	48.3 ± 3.97	69 ± 14.8
		0.06	24	8.0	30
30–39	7	1.75 ± 0.04	168 ± 6.2	48.2 ± 3.21	61 ± 6.4
		0.10	16	8.5	17
40–49	7	1.79 ± 0.02	169 ± 4.6	50.0 ± 2.12	61 ± 5.1
		0.04	12	5.6	14
50–65	7	1.83 ± 0.04	157 ± 6.8	53.7 ± 2.79	61 ± 6.7
		0.09	18	7.4	18

[1] Due to small variations in the pedal frequency the work load is not exact, but the S.D. is less than 3 per cent of the mean.

[2] Two of the included subjects reached maximal values.

[3] Four of the included subjects reached maximal values.

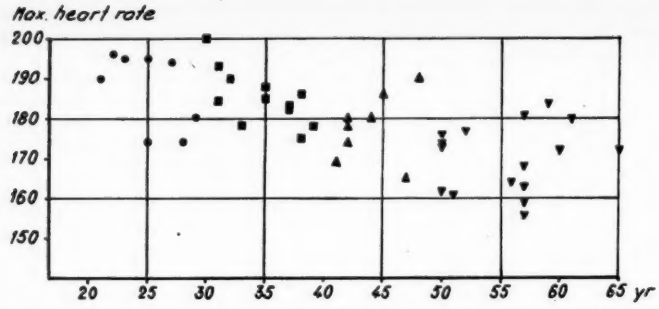

Fig. I: 7. Individual maximal heart rate in relation to age (n = 44). For the symbols see Fig. I: 6.

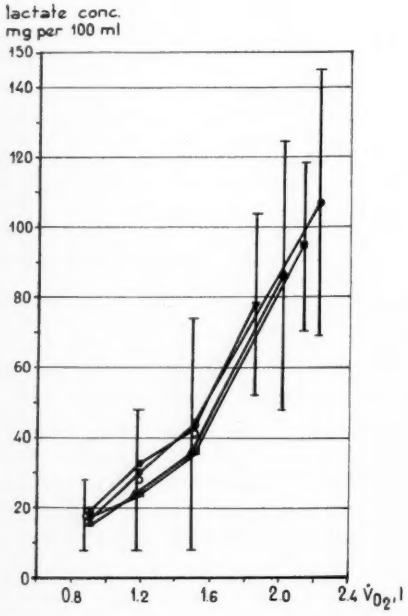

Fig. I: 8. Blood lactate concentration in relation to oxygen uptake ($\dot{V}O_2$; STPD) for the different age groups (n = 44). For the symbols see Fig. I: 6.

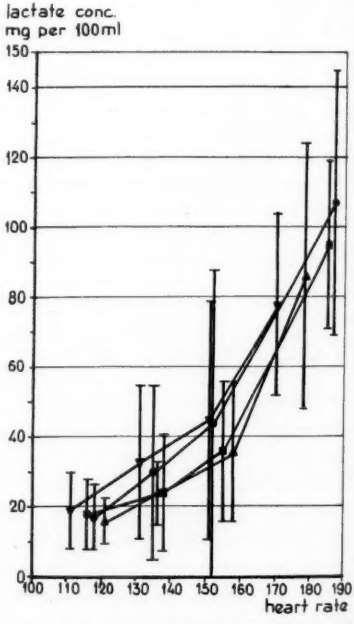

Fig. I: 9. Blood lactate concentration in relation to heart rate for the different age groups (n = 44). For the symbols see Fig. I: 6.

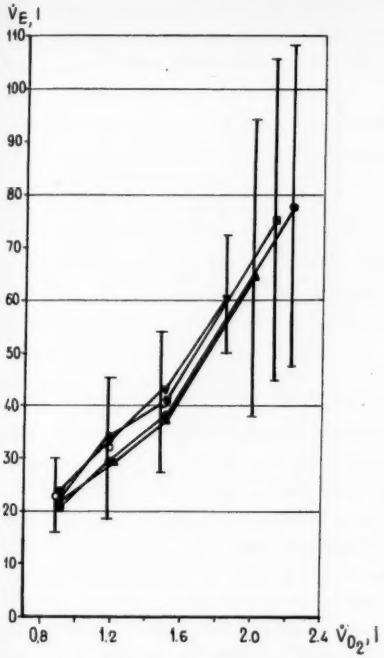

Fig. I: 10. Pulmonary ventilation ($\dot{V}_E$; BTPS) in relation to oxygen uptake ($\dot{V}O_2$; STPD) for the different age groups (n = 44). For the symbols see Fig. I: 6.

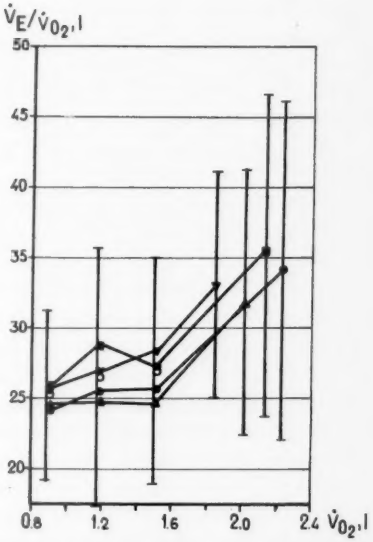

Fig. I: 11. Ratio of pulmonary ventilation ($\dot{V}_E$: BTPS) to oxygen uptake ($\dot{V}O_2$; STPD) in relation to oxygen uptake (STPD) for the different age groups (n = 44). For the symbols see Fig. I: 6.

values ± 2 S.D. (1 S.D. = about 6 per cent) are given for all subjects. The corresponding heart rates for the different age groups are seen in Fig. I: 6. The maximal values are also included in the figure. It can be seen that there is an approximate rectilinear relationship between heart rate and $\dot{V}o_2$ in all age groups. However, the maximal heart rate recorded falls gradually from 187 for the youngest group to 170 for the oldest. This decrease in maximal heart rate is clearly evident from Fig. I: 7. The peak blood lactate concentrations measured after the various work loads are given in relation to the exercise level of $\dot{V}o_2$ and heart rate in Fig. I: 8 and I: 9. The rapid increase in concentration of this anaerobic metabolite with increasing work load is evident. The very pronounced individual variations in the blood lactate at fixed levels of oxygen intake or heart rate during work is obvious from the figures.

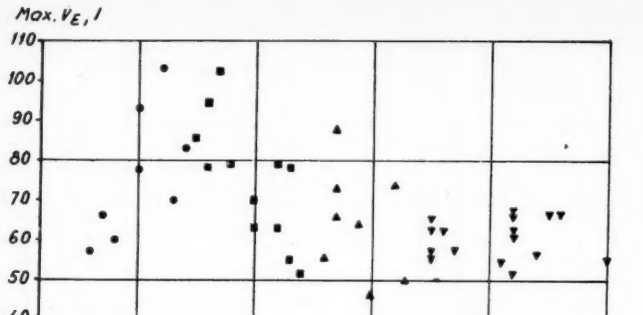

Fig. I: 12. Individual maximal pulmonary ventilation ($\dot{V}_E$; BTPS) in relation to age (n = 44). ● = 20—29; ■ = 30—39; ▲ = 40—49 and ▼ = 50—65 years, female subjects.

The maximal and submaximal pulmonary ventilations, both total and per l of $\dot{V}o_2$, for the different age groups are plotted against $\dot{V}o_2$ in Fig. I: 10 and I: 11. The maximal $\dot{V}_E$ averaged 76.2 l for the youngest group and 60.5 for the oldest. The individual data are given in Fig. I: 12. The ratio of $\dot{V}_E/\dot{V}o_2$ did not vary with age but with work load. At submaximal work it was about 26 l and at maximum about 32—35 l.

Discussion

MAXIMAL WORK

a) *Oxygen uptake, blood lactate concentration.* In the youngest group the mean maximal oxygen uptake is 2.23 l/min with a mean blood lactate concentration of 107 mg per 100 ml. The oxygen uptake is 23 per cent lower than in P.-O. ÅSTRAND's (1952) group who had a $\dot{V}o_2$ value of 2.90 l/min and a lactate concentration of 104 (see Table I: III). This difference in maximal oxygen uptake is significant ($P < 0.001$). The great difference might partly depend upon a difference in body size, since there is a good correlation between maximal $\dot{V}o_2$ during cycling and running and body size in these younger subjects without excessive amount of fat (P.-O. ÅSTRAND 1952, p. 106). The average height is the same in the two groups, 166 cm, but the average weight differs somewhat, 56.2 in the present and 60.3 kg in the other group. Based on the supposition

that this difference in body weight might eventually indicate a difference in lean body weight, the figures for maximal $\dot{V}o_2$ per kg body weight are also compared. The difference between the groups is then slightly reduced, to 18 per cent, but remains significant at the 0.1 per cent level. It may thus be concluded that the difference certainly depends both upon inherited physical traits concerning the circulatory parameters and different degrees of physical training in the two groups of subjects, one consisting of active housewives and the other of well-trained physical education students. Concerning the relationship between total amount of hemoglobin (blood volume) and body weight and height, see SJÖSTRAND (1949) and P.-O. ÅSTRAND (1952, p. 45, 46).

The average maximal $\dot{V}o_2$ decreases with age with 17 per cent from 2.23 in the youngest to 1.85 l/min in the oldest group. See Table I: III and Fig. I: 3. The maximal blood lactate concentration attained in the blood decreases with age from 107 to 78 mg per 100 ml, as seen in Table I: III. With regard to the physical strain during "maximal work", see Methods.

In this case it is necessary to investigate whether or not this difference in maximal oxygen uptake can be explained as a difference in lean body weight of the groups. Here no assumptions can be drawn on the basis of figures for total body weight, because average fat content is different in different ages. The body height, however, is also different and this indicates a difference in lean body weight between the groups. When only height is known lean body weight is best predicted as a linear function of height cubed (v. DÖBELN, 1959). For dimensional reasons, physical power is proportional to the lean body weight raised to 2/3, which means that, in this case, it is best predicted as proportional to height squared. The quotient between the squared heights of the groups is 0.929 ± 0.016. The quotient between the figures for maximal oxygen uptake is 0.831 ± 0.043 and the difference is significant ($P < 0.05$). This means that the difference in maximal oxygen uptake between these age groups cannot be justifiably explained as depending upon a difference in body size alone.

In the author's results there is an unequivocal decrease in the capacity for oxygen uptake with age. This is in agreement with the first investigation made in this field by ROBINSON (1938). It is also in agreement with LANGE ANDERSEN's (1959, p. 45 ff) studies of CO_2 recovery time after moderate exercise in adults 20 to about 90 years of age. "The lowest recovery time was observed in the ages between 20 and 30. From the age of 30 the recovery time increases and in men is about doubled at the age of 70" indicating a "deterioration of respiratory and circulatory fitness which occurs as an effect of ageing". However, it should be mentioned here that the S.D. of each age group is fairly large. Consequently there are several in the oldest age group who have a higher aerobic work capacity than some in the youngest group. This is in agreement with other studies concerning problems of age, see for instance WELFORD (1958, p. 71).

With regard to $\dot{V}o_2$ per kg body weight, a still greater decrease is obtained when comparing the oldest with the youngest group. The same results were obtained in draymen engaged by three breweries in Stockholm (I. ÅSTRAND, 1958 a). In the present material, the difference increases from 17 to 29 per cent, depending upon the higher body weight of the older subjects, see Table I: III.

The aerobic capacity in relation to weight is fairly uniform for children after puberty and young adults, see P.-O. ÅSTRAND, 1952, p. 108. This is, however, not the case for the age range 20—65 years. A decrease with increasing age must be considered here, see Fig. I: 4.

b) *Heart rate.* The maximal heart rate is only 187 in the youngest group (S.D. = 10 beats) compared to 198 in P.-O. ÅSTRAND's group of physically well-trained students (see Table I: III; S.D. = 10 beats). The reason for this significant difference ($0.01 > P > 0.001$) may be a difference in the selection of the two materials. In the author's group there were two subjects who reached a maximal heart rate of only 174.

In the present material the maximal heart rate decreases with age from 187 to 170, see Table I: III and Fig. I: 7. This is in agreement with P.-O. ÅSTRAND's material of 1952, p. 30, when comparing 16—18-year-old children with young adults of the same body height. The same was noted by ROBINSON (1938); I. ÅSTRAND (1958 a) and I. ÅSTRAND, P.-O. ÅSTRAND and RODAHL (1959). Furthermore, v. DÖBELN *et al.* (1959) investigated 20 pilot candidates 20 years old and 20 air force pilots 40 years old when they performed work on a bicycle ergometer. They found a maximal heart rate in the first group of 204 ± 1.6 and in the second group of 185 ± 2.6. This difference is significant ($P < 0.001$). The blood lactate concentration was 107 ± 5.6 and 108 ± 4.2 respectively, without any significant difference. Therefore there is no doubt that young people can reach a higher heart rate level than old people, at least when performing such types of work as bicycling and running.

c) *Pulmonary ventilation.* The volume of the pulmonary ventilation primarily depends upon the absolute work load. The maximal $\dot{V}o_2$ decreases with about 17 per cent from the youngest to the oldest group (Table I: III) and the corresponding $\dot{V}_E$ with about 21 per cent (Table I: IV and Fig. I: 12). The differences between the young group of P.-O. ÅSTRAND (1952) and the present oldest group are about 36 per cent for $\dot{V}o_2$ and 33 per cent for $\dot{V}_E$. The decrease in total ventilation with ageing evidently follows the decrease in $\dot{V}o_2$.

In order to obtain more information about the ventilation, the ratio $\dot{V}_E/\dot{V}o_2$ was calculated. This value is high in all age groups and amounts to 34.1, 35.2, 31.8 and 33.1 l compared to 32.3 in P.-O. ÅSTRAND's (1952) group, without any positive age difference. The hyperventilation thus demonstrated in all ages is typical for very heavy muscular work when anaerobic processes are greatly involved. Similarly the respiratory frequency (f) is very high (see Table I: IV).

There is, however, a difference in f and in the ratio of the tidal volume (V_T) to the vital capacity (FVC) between the age groups (Table I: IV). Therefore, there might be a difference in the alveolar ventilation per l of oxygen intake ($\dot{V}_A/\dot{V}o_2$). (For the vital capacity see part III.) $\dot{V}_A$ was calculated as: $\dot{V}_E - (V_D + 0.05)$ f. There are evidences reported in literature that V_D (dead space) increases with increasing V_T. ASMUSSEN and NIELSEN (1956) presented figures for V_D at different values for V_T. Their values for males were used in the calculations. The relationship between V_D and V_T might be different for females, but it was considered better to use a progressively increasing V_D instead of fixing it at a certain value. The value of 0.05 l represents the dead space of the mouthpiece and the valve.

The calculated alveolar ventilation per l of oxygen uptake at maximal work has a tendency to decrease with increasing age (Table I: IV). The lower $\dot{V}_A/\dot{V}o_2$ for the older subjects might be interpreted as a result of a weaker stimulus for ventilation, caused by lower lactic acid concentrations in the blood. It may also be a result of an inability to increase the ventilation, due simply to a muscular and anatomical relationship (compare part III).

The maximal diffusing capacity of the lungs (Do_2) decreases with increasing age. This was first convincingly shown by COHN *et al.* (1954). They investigated 21 normal male subjects ranging in age from 17 to 76 years. According to their regression equation a 25-year-old male has a Do_2 of about 59 ml O_2/min/mm mean oxygen gradient, and a 56-year-old has about 42. This means a decrease of 29 per cent. It is unlikely that there should be any difference in this respect between the two sexes. The decrease in the capacity for oxygen uptake for the corresponding ages in the present investigation is 17 per cent. If the two materials are comparable it means that Do_2 decreases faster with age than the maximal $\dot{V}o_2$. COHN's *et al.* results imply that *one* limiting factor for oxygen transport in heavy exercise for older people might be the diffusing capacity of the lungs. However, this is probably not the case in younger subjects (cf. P.-O. ÅSTRAND, 1956; HOLMGREN and LINDERHOLM, 1958). For a discussion of the diffusing capacity as a limiting factor for physical work in patients with different circulatory and pulmonary diseases, the reader is referred to LINDERHOLM (1959).

SUBMAXIMAL WORK

a) *Oxygen uptake.* As can be seen from Table I: V, the means for $\dot{V}o_2$ at different work loads are fairly similar for the four age groups and the standard deviations are comparatively low. On all four work loads the $\dot{V}o_2$ increases, however, somewhat with age. For further discussion and for mechanical efficiency see part II.
b) *Heart rate and blood lactate concentration.* The most striking impression from Fig. I: 6 and I: 8 is the small variation between the age group means for heart rate and blood lactate concentration at different submaximal $\dot{V}o_2$, in contrast to the large variation within the groups. From this it should be clear

that the variation in the circulatory response both to submaximal and maximal work is very large, even within a relatively homogeneous group of "healthy" persons. The variation is certainly even more pronounced in the whole population, including well-trained athletes, convalescents and persons without a well established state of health.

The heart rate on 600 kpm/min averaged 154 beats/min (S.D. 16.4) for all subjects. It is only somewhat lower than the values given by GEMZELL, ROBBE and STRÖM (1957) and ROBBE (1958). These authors examined altogether 39 healthy young pregnant women (mean age 25 and 30 years respectively) during and after pregnancy and found a fairly stable heart rate value during the whole observation time (about 160 beats/min on this load, S.D. ca 13).

Despite the apparent identical reaction to submaximal work of average young and old persons, however, there is a marked difference in their aerobic work capacities (see Table I: V and Fig. I: 6, I: 8 and I: 9). It should be mentioned here that if one had a larger material, a difference in lactate concentration might be seen at submaximal work, compare HOLMGREN and STRÖM, 1959.

c) *Pulmonary ventilation.* There is no age difference regarding $\dot{V}_E$ or $\dot{V}_E/\dot{V}o_2$ in relation to submaximal $\dot{V}o_2$ (see Fig. I: 10 and I: 11). The mean values $\pm$ the standard errors of the means of $\dot{V}_E/\dot{V}o_2$ for the whole group of 44 subjects at the three submaximal work loads are 25.2 ± 0.46, 26.7 ± 0.72 and 26.9 ± 0.61. When calculating from a work load which demanded 60—70 per cent of the individual's aerobic capacity, a value of 24.5 ± 0.5 was obtained by P.-O. ÅSTRAND (1952, p. 75). In the present material the work load of 450 kpm/min corresponds to about 60 per cent of the mean aerobic capacity. The difference between the values for $\dot{V}_E/\dot{V}o_2$ at the 60 per cent work level is significant ($0.02 > P > 0.01$). The calculated ratio $\dot{V}_A/\dot{V}o_2$ at 450 kpm/min is, for the four age groups: 20.4, 22.9, 19.5 and 21.6, with a S.D. of about 3.3 l. The corresponding figure in P.-O. ÅSTRAND's material is 20.4. The difference in $\dot{V}_A/\dot{V}o_2$ at submaximal work is not significant neither between the four age groups nor between the present material and P.-O. ÅSTRAND's well-trained students. Evidently the difference in $\dot{V}_E/\dot{V}o_2$ between the last-mentioned groups depends upon that the present subjects do not utilize the respired air as efficiently as the well-trained students.

PART II

MECHANICAL EFFICIENCY OF YOUNG AND OLD PEOPLE AT LOW AND HIGH WORK LOADS DURING CYCLING

Introduction

The aim of the present investigation was to determine the mechanical efficiency at various work loads on the bicycle ergometer and to find out if there is any significant variation in this efficiency with age and sex. The value ordinarily given in literature for mechanical efficiency during cycling is about 22—23 per cent for both males and females (P.-O. ÅSTRAND, 1952, p. 138). His determinations were made at work loads of 600—1,500 kpm/min and the subjects were young adults. For more detailed information on mechanical efficiency at various activities, the reader is referred to PASSMORE and DURNIN (1955) and P.-O. ÅSTRAND (1956).

During the last ten years an increasing number of patients have been tested on the bicycle ergometer for diagnostic or other reasons. Quite often the work load must be as low as 100 or 200 kpm/min. To simplify the testing procedure the determination of the actual oxygen uptake at a given work load is often omitted and the work load in kpm/min or watt is used instead of the oxygen uptake as the abscissa for evaluation. This will be justified only in case of constant mechanical efficiency and may lead to rather large errors if the efficiency is unknown. This is especially the case if an extrapolation to a higher load is made (cf. part V). Further on, this simplified procedure may give false results if steady state regarding oxygen uptake is not obtained and part of the energy output is provided by anaerobic processes.

Material

The female subjects are described in more detail in part I, p. 11. They ranged between 20 and 65 years of age. The male subjects represent three different materials. The first one was described by I. ÅSTRAND (1958 a). The subjects ranged in age between 50 and 64 years. The second was described by I. ÅSTRAND, P.-O. ÅSTRAND and RODAHL (1959) and were Americans in the age group 56—68 years. The third material consisted of Swedish and American persons who took part in an investigation on physical training. The values measured after a training period of about 6 weeks were used (previously unpublished results). Their age ranged between 27 and 45 years. For further data from this material see part V. For comparison, the results from P.-O. ÅSTRAND's (1952)

TABLE II: I. *Mean value ± standard error of the mean and S. D. of the oxygen uptake at different work loads in different ages for female and male subjects. P.-O. Åstrand's (1952) and Ryhming's (1953) values for healthy well-trained students are included*

n = number of subjects

age, yr.	n	300 kpm/min	n	450 kpm/min	n	600 kpm/min	n	900 kpm/min
present material								
♀ 20–29	8	[1]0.86 ± 0.02 0.06	5	1.16 ± 0.02 0.05	—	—	—	—
30–39	12	0.90 ± 0.02 0.06	10	1.17 ± 0.03 0.08	—	—	—	—
	—	—	—	—	13	[2]1.47 ± 0.01 0.05	—	—
40–49	8	0.90 ± 0.02 0.04	7	1.18 ± 0.02 0.04	—	—	—	—
50–65	15	0.95 ± 0.02 0.09	9	1.21 ± 0.02 0.06	—	—	—	—
R-G (1953)								
♀ 20–26	—	—	—	—	31	1.48 ± 0.02 0.10	—	—
P.-O. Å-D (1952)								
♀ 20–25	—	—	—	—	31	1.48 ± 0.02 0.08	31	2.06 ± 0.02 0.09
unpubl. material								
♂ 27–45	16	0.95 ± 0.01 0.05	9	1.23 ± 0.02 0.05	12	1.52 ± 0.02 0.06	—	—
I. Å-D (1958 a) I. Å-D *et al.* (1959)								
♂ 50–68	9	0.99 ± 0.02 0.07	5	1.26 ± 0.03 0.06	55	[3]1.59 ± 0.02 0.12	18	[3]2.19 ± 0.03 0.13
R-G (1953)								
♂ 22–31	—	—	—	—	—	—	29	2.15 ± 0.02 0.10
P.-O. Å-D (1952)								
♂ 20–33	—	—	—	—	—	—	21	2.09 ± 0.02 0.09

[1] = this value is significantly lower than that for the oldest group, $0.01 > P > 0.001$.

[2] = this value represents a mean value for all age groups (although it includes only two subjects in the oldest).

[3] = the work loads were not always kept exactly at 600 and 900, and this is mirrored in a higher S. D., cf. I. Å-D (1958 a).

TABLE II: II. *Mean value ± standard error of the mean and S. D. for the mechanical efficiency at different work loads in different ages for female and male subjects. P.-O. Åstrand's (1952) and Ryhming's (1953) values for healthy well-trained students are included*

n = number of subjects

age, yr.	n	300 kpm/min	n	450 kpm/min	n	600 kpm/min	n	900 kpm/min
present material								
♀ 20–29	8	[1] 21.9 ± 0.66 1.9	5	[2] 22.7 ± 0.50 1.1	–	–	–	–
30–39	12	20.7 ± 0.48 1.7	10	22.5 ± 0.48 1.6	–	–	–	–
	–	–	–	–	13	[3] 22.5 ± 0.27 1.0	–	–
40–49	8	20.6 ± 0.30 0.9	7	22.3 ± 0.22 0.6	–	–	–	–
50–65	15	19.6 ± 0.35 1.4	9	21.4 ± 0.41 1.3	–	–	–	–
R-G (1953)								
♀ 20–26	–	–	–	–	31	22.7 ± 0.27 1.5	–	–
P.-O. Å-D (1952)								
♀ 20–25	–	–	–	–	31	22.5 ± 0.3 1.6	31	23.1 ± 0.2 1.1
unpubl. material								
♂ 27–45	16	[1] 20.8 ± 0.33 1.3	9	[2] 22.2 ± 0.39 1.2	12	[1] 22.9 ± 0.27 0.9	–	–
I. Å-D (1958 a) I. Å-D et al. (1959)								
♂ 50–68	9	18.9 ± 0.47 1.4	5	20.9 ± 0.54 1.2	55	21.8 ± 0.22 1.6	18	22.6 ± 0.34 1.4
R-G (1953)								
♂ 22–31	–	–	–	–	–	–	29	22.8 ± 0.21 1.1
P.-O. Å-D (1952)								
♂ 20–33	–	–	–	–	–	–	21	23.4 ± 0.3 1.1

[1] = this value is significantly higher than that for the oldest group, $0.01 > P > 0.001$.
[2] = this value is significantly higher than that for the oldest group, $0.1 > P > 0.05$.
[3] = this value represents a mean value for all age groups (although it includes only two subjects in the oldest).

and RYHMING's (1953) investigations of physically well-trained young subjects are included in Tables II: I and II: II.

Methods

All subjects cycled on KROGH's or v. DÖBELN's (1954) bicycle ergometer with a pedal frequency of 50 revolutions per min. Regarding the determinations of the oxygen uptake ($\dot{V}o_2$) and the lactate concentration in the blood, see part I, p. 13 ff. The individual values usually represent mean values of double determinations in one experiment. In some cases two experiments were conducted. *No values obtained in experiments in which the blood lactate concentration reached higher values than 30 mg per 100 ml have been used in this part of the study.* A work with a blood lactate concentration of about 30 mg per 100 ml at the initial state of work can usually be prolonged for one hour or more without any further increase in this concentration or in $\dot{V}o_2$, compare part VII. This suggests that a blood lactate concentration of this amount at that moment is caused by anaerobic processes at the beginning of the work. If this is true, the work can be performed principally aerobically from about the 4th min.

The net mechanical efficiency was calculated from the following formula:

$$\text{mech. eff.} = \frac{\text{mechanical work performed (kpm/min)} \times 100}{427\ (\text{total Cal. prod./min} - \text{basal Cal. prod./min})}$$

The basal oxygen uptake was calculated according to the Mayo Foundation standard. The caloric coefficient for oxygen was set at 4.825 at rest and at 4.900 during work.

Results

Table II: I presents the values for oxygen uptake from which the mechanical efficiency was calculated (Table II: II). An analysis of the data on young and old subjects shows that the difference in gross oxygen uptake is relatively small. When calculating the mechanical efficiency the variation in basal metabolism with age is considered. This results in a significantly lower mechanical efficiency of the older subjects as compared to the younger, see Table II: II. This is valid for the female subjects at 300 and 450 kpm/min. At 600 kpm/min only 13 subjects had a lactate concentration below 30 mg per 100 ml and a

TABLE II: III. *Mean value ± standard error of the mean and S. D. for the mechanical effi-*
n = number of subjects

	n	without a load	50 kpm/min	100 kpm/min
mech. eff. per cent	5	± 0	10.5 ± 0.56 1.3	15.4 ± 0.61 1.4
$\dot{V}o_2$, l.....	5	0.37 ± 0.02 0.04	0.43 ± 0.02 0.03	0.51 ± 0.02 0.03

mean value for those subjects, irrespective of age, is given. At 600 kpm/min there is no difference between the groups of relatively young housewives and physically well-trained students.

In the male material there is a significantly lower mechanical efficiency at 300 and 600 kpm/min for the oldest group as compared with that for the youngest. The tendency is the same at 450 kpm/min but not at 900 kpm/min. At this latter work load the value for the older group is not significantly different from that of the young, well-trained students. Individuals between 50 and 68 years, who can perform 900 kpm/min with a lower blood lactate concentration than 30 mg per 100 ml, have a high capacity for oxygen uptake. Certainly, these older subjects constitute a selected group. This might be the explanation for their relatively high mechanical efficiency.

At a given work load oxygen uptake of women is lower than that of men. The difference in basal metabolic rate balances so that mechanical efficiency is identical.

Table II: III gives mean values for mechanical efficiency and oxygen uptake at lower work loads for five female subjects 25—35 years old, see also Fig. II: 1. They cycled also without a load[1], at 50, 100, 150 and 200 kpm/min. Their mean values for mechanical efficiency at 300, 450 and 600 kpm/min are higher than the averages in Table II: II. The increase in mechanical efficiency from 50 up to 450 kpm/min is obvious, from 10.5 to 23.5 per cent. An increase from 300 to 450 kpm/min is also observed in all the other age groups (cf. Table II: II).

Discussion

When working submaximally at fixed loads on a bicycle ergometer female subjects take up less oxygen than do males. At very low work loads the oxygen uptake is relatively high. This fact should be kept in mind when examining subjects during cycling where the actual oxygen uptake is not determined.

Obviously, a decrease in mechanical efficiency during cycling takes place with increasing age. The material which forms the foundation for this statement

[1] The braked power without a load on the wheel is 3.14 kpm/min for the bicycle ergometer used. At different work loads, up to a force of 7 kp and at a pedal frequency of 50/min, the measured power is only increased by about 30 kpm/min because of this wastage.

ciency and the oxygen uptake at different lower work loads for five younger female subjects

150 kpm/min	200 kpm/min	300 kpm/min	450 kpm/min	600 kpm/min
18.8 ± 0.63 1.4	20.4 ± 0.47 1.1	22.1 ± 0.33 0.7	23.5 ± 0.37 0.8	23.5 ± 0.25 0.5
0.58 ± 0.01 0.03	0.67 ± 0.01 0.03	0.85 ± 0.01 0.02	1.11 ± 0.02 0.03	1.42 ± 0.01 0.03

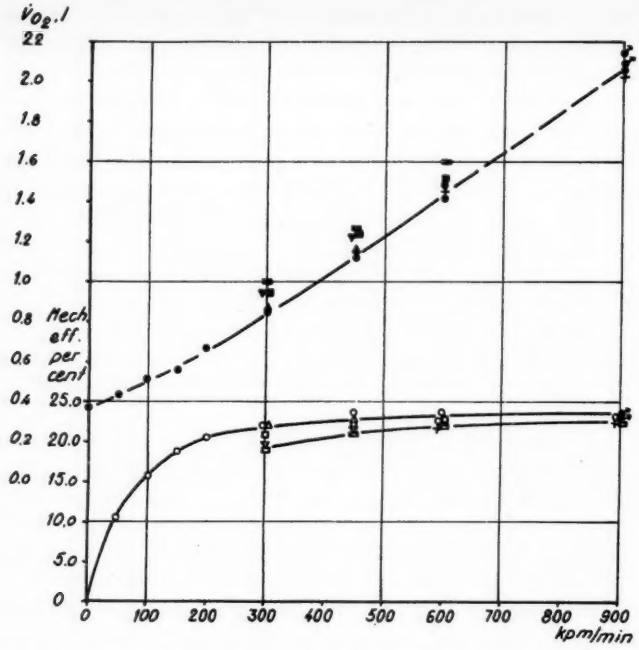

Fig. II: 1. Mechanical efficiency in per cent (unfilled symbols) and corresponding gross oxygen uptake (filled symbols) in relation to work load. ○, ● = five young female subjects; △, ▲ = youngest female group; ▽, ▼ = oldest female group; □, ■ = youngest male group; ▭, ▬ = oldest male group; ♀, ♀ = female and ♂, ♂ = male students.

is relatively homogeneous. It is not likely that a certain selection has occurred, which gives a false picture. If the calculated basal metabolism deviates from the actual, the mechanical efficiency must be incorrect. The difference in mechanical efficiency between the youngest and the oldest female and male groups at 300 kpm/min would correspond to a deviation from the standard value of about 0.08 l/min, or 30—40 per cent (plus for the oldest and minus for the youngest). Such a big discrepancy is unprobable. Systematical errors in this material could not be detected.

In an earlier paper by I. Åstrand (1958 a) it was concluded that 50—64-year-old draymen engaged by three breweries in Stockholm cycled with the same mechanical efficiency as young students. The only work loads that were used for the calculation were 600 and 900 kpm/min, and the difference between the two compared materials was too small to be evaluated as an age difference (cf. Table II: II). Any limit for blood lactic acid concentration was not considered for those subjects included in this previous comparison.

PART III

VITAL CAPACITY AND 1.0-SECOND'S EXPIRATORY CAPACITY IN WOMEN 20—65 YEARS OLD

Introduction

Earlier investigations have shown that vital capacity is relatively uncorrelated with the capacity for oxygen uptake and maximal pulmonary ventilation, as long as one is dealing with adult "healthy" persons, see P.-O. ÅSTRAND (1952, p. 69 ff) and I. ÅSTRAND (1958 b). However, the last-mentioned author found that the correlation between maximal oxygen uptake and residual air in per cent of the total capacity for males 50—64 years old was significant. It was considered to be of interest to investigate how another lung function test, 1.0-sec expiratory capacity, correlated with oxygen uptake capacity in the material of female subjects.

Material and methods

Forty-four 20—65-year-old females were used as subjects. They are presented in part I, p. 11. By means of a KROGH spirometer, fast vital capacity (FVC[1]), measured 4—6 times, and 1.0-second's expiratory capacity (1.0-sec EC[1]), measured 3—6 times, were determined in a sitting position. The highest values of these determinations were used.

Results

Some physical measurements on the subjects are presented as mean values for the age groups in Table I: I, p. 12. FVC decreases significantly with increasing age from 3.79 l for the 20—29-year-old group to 3.24 l for the 50—65-year-old one ($0.01 > P > 0.001$), and 1.0-sec EC from 84.3 per cent of FVC to 79.3 per cent ($0.1 > P > 0.05$).

Discussion

A decreasing FVC with age has been documented in literature several times, for example by ROBINSON (1938) and GREIFENSTEIN *et al.* (1952).

MILLER, JOHNSON and WU (1959) found that their FVC values for 76 females 20—59 years old were about 10—20 per cent higher than in investigations presented earlier. The same holds true for the figures reported here. These two

[1] The symbols used here were proposed by MILLER, JOHNSON and WU (1959), as being acceptable to most respiratory physiologists according to a circulated inquiry.

studies were made on materials consisting of "healthy" persons. Actually, there are existing studies, however, with values of about the same size (BIRATH, 1944, pp. 47, 48) or somewhat higher (P.-O. ÅSTRAND, 1952, p. 61) for a certain age group.

MILLER, JOHNSON and WU (1959) presented a nomogram constructed on the basis of their values for FVC, height and age. On an average, the measured FVC in the present material constitutes 102.5 (S.D. = ± 11.4) per cent of the predicted values from their nomogram. The authors had a corresponding S.D. of ± 10.7 per cent.

Also the values for 1.0-sec EC agree fairly well with those reported by MILLER, JOHNSON and WU (1959). Their figures for the four age groups between 20 and 59 years were: 87.0, 84.5, 81.6 and 81.3 per cent (cf. Table I: I, p. 12). The present values also agree favourably with those given by PEMPERTON and FLANAGAN (1956).

Without a doubt, there is a change in this function with increasing age. The decrease in FVC is probably a result of altered mechanical properties of the chest wall, and decreased muscular force in the respiratory muscles. In measuring 1.0-sec EC in per cent of FVC a time factor is introduced. It is probable that, among other things, a decrease in muscular force is followed by a decrease in the speed of contraction and that this is reflected in the 1.0-sec EC.

The correlation coefficient between oxygen uptake capacity (see part I, p. 26) and 1.0-sec EC was calculated and was 0.255 (P = 0.1). The partial correlation coefficient eliminating the influence of age was also calculated. This was 0.084 (P = 0.6), which indicates that the correlation between maximal oxygen uptake and 1.0-sec EC is insignificant.

PART IV

ELECTROCARDIOGRAMS AT REST AND DURING AND AFTER WORK IN WOMEN 20—65 YEARS OLD

Introduction

Only a few studies are presented in literature on ECG reaction *during* work. One of these is the Stockholm's City Health Survey 1954, in which 242 men and women 40—50 years old were examined during and after work on the bicycle ergometer (Frisk *et al.*, 1957; 1959). Of these, 21 (8.7 per cent) had a pathological and 18 (7.4 per cent) a suspected pathological ECG during and after work. Of the 21 cases with pathological changes, only 6 had a pathological and 5 a suspected pathological ECG already at rest. Seventeen of the 21 with a pathological ECG during and after work got a diagnosis of ischemic heart disease or hypertension with heart strain. However, in three cases this diagnosis was based solely upon the ECG during and after work.

In an investigation of 81 draymen 50—64 years old employed by three breweries in Stockholm the same method for recording and interpretation was used. During and after work the occurrence of pathological and suspected pathological ECG was 15 (19 per cent) and 27 (33 per cent) respectively (I. Åstrand, 1958 b). The number of corresponding rest ECG diagnoses was 3 (4 per cent) and 7 (8 per cent). The clinical examinations resulted in a positive diagnosis of circulatory disease, mainly ischemic heart disease or hypertension, in 38 of these 81 draymen (Önnerstad, personal communication, to be published). Of these 38, only 8 had a pathological or suspected pathological ECG at rest in contrast to 29 during and after work. Of the nine subjects (38 minus 29) without a pathological or suspected pathological ECG at work eight had hypertension and one ischemic heart disease. This last subject, however, had a suspected pathological ECG at rest. Of the remaining 43 cases without a positive diagnosis of circulatory disease, 2 had a suspected pathological ECG at rest; 10 had a suspected pathological and 3 a pathological ECG during and after work, see Table IV: I.

All in the above-mentioned group were engaged in a relatively heavy occupation. No significant difference in the capacity for oxygen uptake was found in the subjects with a pathological or a suspected pathological ECG in comparison to those with a normal or slightly different from normal ECG.

These observations indicate that ECG recordings during and after exercise are an important contribution to the objective methods available for early diagnosis of ischemic heart disease.

It has repeatedly been reported that ischemic heart disease appears quite

TABLE IV: I. *Frequency of various ECG diagnoses occurring in the two groups (with and without a diagnosis of circulatory disease) of draymen. For the classification in the four groups see I. Åstrand (1958 b)*

1 = normal ECG
2 = slightly different from normal ECG
3 = suspected pathological ECG
4 = pathological ECG

	1	2	3	4	total number
with a diagnosis of circulatory disease: "rest" ECG..	5	25	5	3	38
"work" ECG..	3	6	16	13	38
without a diagnosis of circulatory disease: "rest" ECG..	16	25	2	0	43
"work" ECG..	14	16	11	2	43

frequently even in young persons (YATER *et al.*, 1948; ENOS, HOLMES and BEYER, 1953; KEIL and MCVAY, 1957). However, the materials of younger subjects found in literature on which this technique (ECG recorded during muscular exercise) has been used are small. HOLMGREN (1956, p. 20) found no pathological ECG changes during or after maximal exercise on a bicycle ergometer in 17 well-trained athletes. KLEIPZIG, MÜLLER and REINDELL (1956) used one load in 14 healthy, young subjects and found only normal variations in extremity leads.

When 44 female persons 20—65 years old were carefully examined for their capacities for oxygen uptake and related functions, it was also considered to be of great interest to record ECG during and after work.

Material

Forty-four female subjects were examined. Eight were 20—29, 12 were 30—39, 8 were 40—49 and 16 were 50—65 years old. All of them considered themselves "healthy" at the time of the investigation. For more details about the material see part I, p. 11.

A careful clinical examination including medical history initiated the series of experiments. The arterial blood pressure was measured in a recumbent position on the left arm with a mercury manometer. The upper limit for a normal systolic pressure was set at 165 mm Hg, and for diastolic at 95 mm as in Stockholm's City Health Survey (FRISK *et al.*, 1957). Urine collected in the morning was tested for the presence of albumin and reducing substances. The hemoglobin level was determined by a spectrophotometric analysis. If the value was less than 10.7 g per 100 ml, anaemia was considered to exist. Vital capacity and 1.0-sec expiratory capacity were determined. All values exceeding predicted values $-2 \times$ S.D., according to MILLER, JOHNSON and WU (1959), were considered as normal values for vital capacity. The same

authors' averages — 2 × S.D. were used concerning the 1.0-sec expiratory capacity. The methods and the results of these tests are given in part III, p. 33.

No subjects were treated with digitalis. Four had medical histories of suspected angina pectoris, 2 in the 40—49 and 2 in the 50—65-year-old group. Of these *only one* (56 years old) had suspected ECG recordings during and after work (several premature auricular beats on the higher work loads and premature ventricular beats on the highest work load, group 3, see later). Two were anaemic (9.3 and 10.6 g per 100 ml hemoglobin) but the fourth subject showed no abnormalities. Anaemia existed in one more subject (10.4 g hemoglobin per 100 ml, normal ECG recordings). One subject in the 50—65-year-old group had a mild hypertension (150/100 mm Hg) without any other remarkable findings. One subject in the 20—29-year-old group had a lower value for vital capacity than the predicted — 2 × S.D. Her pulmonary ventilation per liter of oxygen uptake was, at submaximal work, 24.1 l; the corresponding mean for all the others was 26.7 ± 0.72 l. In all cases the 1.0-sec expiratory capacities were higher than 70.1 per cent. None of the 44 subjects showed presence of reducing substances or albumin in the urine.

During exercise none of the subjects had subjective symptoms of such a type that the work test had to be discontinued before the criteria for maximal work were reached, as specified in part I, p. 12.

Methods

ECG was recorded after about 5 min rest ("rest" ECG), frequently during each work load, immediately after and approximately 4 min after each work load. The diagnosis for the "work" ECG is based upon all these different recordings. Each of the leads could be instantly selected and continuously inspected on a one-channel cardioscope. For the work tests, see part I, p. 11. The procedure was repeated 3—7 times on different days. For the recordings, the Elema's "Klinik" apparatus was used, with the ordinary extremity leads I, II and III, and five chest leads CR_1, CR_2, CR_4, CR_5 and CR_7 at rest, and four chest leads, HR_2, HR_4, HR_5 and HR_7 during work. The reference electrode was placed on the forehead (H = head) during cycling.

The author interpreted all of the ECGs. Both the "rest" and the "work" ECG recordings were classified into four groups: normal ECG (group 1), slightly different from normal (group 2), suspected pathological (group 3) and pathological ECG (group 4). For literature see FRISK *et al.*, 1957; SANDBERG, 1957 and I. ÅSTRAND, 1958 b. The "rest" ECGs were interpreted according to the general rules used in Sweden (mainly as given by GREWIN, 1948, p. 156 ff).

In a material of 81 subjects the ECGs were interpreted independently by the author and another person (I. ÅSTRAND, 1958 b). With regard to the classifica-

TABLE IV: II. *"Rest" and "work" ECG changes and their different classification as observed in the four age groups of 44 female subjects. In many cases several changes were recorded in the same subject*

Classification: 1 = normal ECG
2 = slightly different from normal ECG
3 = suspected pathological ECG
4 = pathological ECG

	classification	occurrence of changes				number total
		20—29 yr.	30—39 yr.	40—49 yr.	50—65 yr.	
"rest" ECG changes						
heart rate above 90/min (sinus tachycardia)	2	1	2	1	2	6
occasional premature auricular beat(s) or abnormal P	2	0	1	0	2	3
S-T junction depression less than 1 mm	2	0	1	2	4	7
S-T junction depression less than 1 mm in combination with a flat T	3	0	2	0	0	2
"work" ECG changes						
occasional premature auricular beat(s) or abnormal P during and after work	2	4	4	0	3	11
series of premature auricular beats which appear during or after work	3	0	0	0	2	2
occasional premature ventricular beat(s) during or after work	2	0	0	2	3	5
several premature ventricular beats only after work	3	0	0	0	1	1
increased number of premature ventricular beats with increasing work load or beats from two or more foci	4	0	0	0	1	1
S-T junction depression *only* during work	2	1	2	1	5	9
S-T junction depression 0.5—0.9 mm *and* S-T segment horizontal or downward sloping during and after work	3	0	1	1	3	5
S-T junction depression 0.5 mm or more *and* S-T segment horizontal or downward sloping which is accentuated 4 min after work, or S-T junction depression 0.5 mm or more in combination with a negative T	4	0	1	1	3	5

tion in the 1—2 or 3—4 group there was a difference of opinion about five recordings at rest (6 per cent) and six at work (7 per cent).

The two most common findings which appear in a work test are arrhythmias and S-T junction changes. Of the arrhythmias, the presence already at rest or appearance of occasional premature auricular beats during or after work

Fig. IV: 1. "Rest" and "work" ECGs on a subject (63 years old) with the appearance of many premature ventricular beats *only during* the maximal load (600 kpm/min). The "rest" ECG was placed in group 1 and the "work" ECG in group 4. The leads used are, at rest: I, II, III, CR_1, CR_2, CR_4, CR_5 and CR_7, during work: HR_2, HR_4, HR_5, and HR_7, H = head.

Fig. IV: 2. An example of a subject (57 years old) with "rest" ECG in group 1 and "work" ECG in group 4. The pathological change consists of the appearance of S-T changes during and after work. The S-T junction is increasingly depressed during work with increasing work loads. The S-T segment is horizontal 4 min after 300 and 600 kpm/min, but downward sloping 4 min after 900. For the leads see Fig. IV: 1.

TABLE IV: III. *Occurrence of "rest" and "work" ECG diagnoses in the four age groups of female subjects*

n = number of subjects
1 = normal ECG
2 = slightly different from normal ECG
3 = suspected pathological ECG
4 = pathological ECG

age group yr.	n	"rest" ECG				"work" ECG			
		1	2	3	4	1	2	3	4
20–29	8	7	1	0	0	4	4	0	0
30–39	12	6	4	2	0	7	3	1	1
40–49	8	5	3	0	0	3	3	1	1
50–65	16	9	7	0	0	3	6	3	4

was judged as slightly different from normal and referred to group 2; series of such beats, however, was referred to group 3. The presence already at rest or appearance of occasional premature ventricular beats during or after work was referred to group 2 (cf. I. ÅSTRAND, P.-O. ÅSTRAND and RODAHL, 1959), the appearance of several premature ventricular beats after work to group 3, and increasing numbers with increasing work load to group 4 (see Table IV: II and Fig. IV: 1). Regarding the evaluation of the presence of premature ventricular beats, compare MANN and BURCHELL (1952). S-T junction depression which appeared *during* work but disappeared during normalization of the heart rate after work was referred to group 2 (cf. MASTER, FRIEDMAN and DACK, 1942; GROSSMAN, WEINSTEIN and KATZ, 1949; SJÖSTRAND, 1950 and 1951). S-T junction depression 0.5—0.9 mm *and* S-T segment horizontal or downward sloping which appeared during work and remained afterwards was referred to group 3. S-T junction depression 0.5 mm or more *and* S-T segment horizontal or downward sloping which appeared during work and was *accentuated* 4 min after work or S-T junction depression 0.5 mm or more in combination with a negative T was referred to group 4 (see Table IV: II and Fig. IV: 2). Compare for instance MASTER, PORDY and CHESKY, 1953; SANDBERG, 1957 and FRISK *et al.*, 1957. In 1952 a comprehensive review of the literature on exercise tests with a critical evaluation of the techniques and the interpretations was published by SCHERF and SCHAFFER.

Results

The different ECG observations on "rest" and "work" ECG with their classifications are found in Table IV: II. The occurrence of the 4 ECG diagnoses at rest and at work in the four age groups is given in Table IV: III.

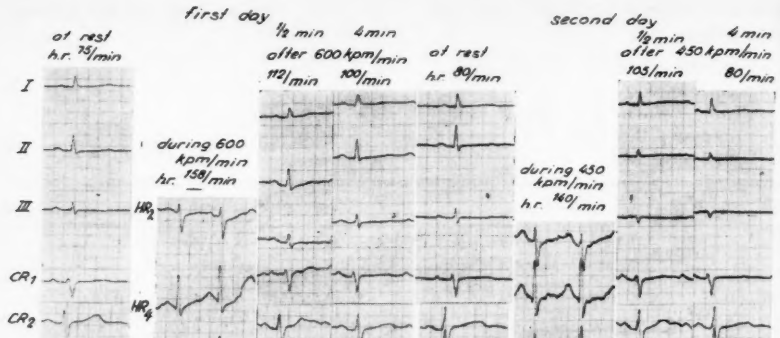

Fig. IV: 3. ECGs on two different days with one week's interval. The S-T change is more pronounced both at rest and at work on the second day as compared with the first, a variation which is typical for so-called sympathicotonic reaction. For the leads see Fig. IV: 1.

"REST" ECG RECORDINGS

No subjects were placed in group 4 from the "rest" ECGs; 2 persons, both in the 30—39-year-old group, were referred to group 3 because of S-T junction depression in combination with a low T, which in both cases might depend partly upon a so-called sympathicotonic reaction. (At work one of these subjects remained in group 3 and the other came under group 4.) As a comparison it may be mentioned that in Stockholm's City Health Survey, 1954, there were 2.7 per cent in group 4 and 4.3 per cent in group 3 in the corresponding age groups (Frisk *et al.*, 1957; 1959).

The reproducibility of the ECG recordings in group 1 and 2 was very good. In the two subjects classified in group 3 variations in the S-T changes were observed from one day to another. This is not unusual when dealing with S-T changes of so-called sympathicotonic type (see Fig. IV: 3). Cf. for instance Holmgren *et al.* (1959 b).

"WORK" ECG RECORDINGS

All subjects 20—29 years old had a normal or practically normal "work" ECG; in the 30—39 years group, one came in group 3 and one in group 4 as mentioned above; in the 40—49 years group one appeared in group 3

and one in group 4; in the 50—65 years group three were in group 3 and four in group 4 (see Table IV: III).

With only one exception, the subjects who were classified differently on different work loads came in a higher group at higher work loads. Of 11 subjects with "work" ECG in group 3 or 4, 4 were so classified solely from the maximal work load (2 cases with S-T changes and 2 cases with ventricular premature beats), and 3 solely from the two highest work loads (S-T changes). The remaining 4 came in the same group for all the work loads (3 cases with S-T changes and one case with both S-T changes and ventricular premature beats). Only the last four would have been placed in the same groups if ECG had been recorded only during recovery. This means that 7 out of 11 persons would have been diagnosed into groups 1—2 instead of groups 3—4 if ECG had been recorded only after work and not during work.

The maximal oxygen uptake and maximal heart rate values for the eleven subjects placed in groups 3—4 do not differ significantly from the corresponding mean values for the subjects placed in groups 1—2 in the different age groups. (Cf. I. Åstrand, 1958 b; I. Åstrand, P.-O. Åstrand and Rodahl, 1959.)

Discussion

The present investigation indicates that considerably more ECG changes may appear at *increasing work loads* as compared to at only one submaximal work load or only during recovery from work. It is obvious that the former method is more informative. This is in agreement with the observations by Yu and Soffer (1952) who obtained false negative tests in about 20 per cent of the cases of angina pectoris when recordings were not made *during* exercise. Compare also Yu *et al.*, 1951. This also agrees with observations by Simonson and Keys (1956), who pointed out that for most patients with coronary insufficiency there seems to be a critical level of exercise below which the response is normal and above which it is abnormal. They used walking on a treadmill as the exercise test and recorded ECG after work. Regarding the question as to whether an exercise test such as a stair case test (Nylin, 1933, p. 10 ff) with ECG recording only after work is more valuable than an anoxemia test, Björck (1946 b) came to the conclusion that the tests gave about similar results. Both the two last-mentioned tests are probably inferior to a test with increasing, well defined work loads with ECG recorded both during and after the work.

A work test which includes a maximal load may be unsuitable in a clinical examination. Whether or not the risks of such a test are greater than if one always stops at an early stage or only uses an arbitrarily chosen submaximal work load is difficult to evaluate. One pre-requisite for using a maximal test is naturally that the test is carried out with continuous ECG control and in

the presence of a competent physician who can decide whether the test should be discontinued before a maximal or other predetermined value has been reached. It is notable that none of the 44 female subjects and only 2 of 74 draymen (I. ÅSTRAND, 1958 b) complained about such strong subjective symptoms that the test had to be discontinued, despite the fact that all of them performed maximal or close to maximal work for several minutes.

However, we do not know whether these ECG changes on the whole mean anything for persons who do not have the slightest symptom of coronary heart disease. The whole problem of ischemic heart disease was recently expressed by BIÖRCK (1960) in the following concise and explicit way: "What does 'coronary heart disease' mean in an epidemiological sense as compared to 'clinical coronary heart disease'?" In the present investigation there were 11 subjects with a pathological or suspected pathological "work" ECG, and only one of these had a history of angina pectoris. In 1950 BIÖRCK and DALHAMN pointed out that there are no grounds for maintaining that the results of the test (stair case test with ECG recorded after work) when conflicting with the clinical evaluation as such, would be more valuable than the latter. Compare also BIÖRCK, 1946 a. On the other hand, the changes in these subjects are of the same type as in patients with ischemic heart disease, and therefore it is reasonable to assume that these ECG changes represent early signs of coronary heart disease before any other signs or symptoms are evident. At any rate, it may be wrong to accept these changes as normal or false reactions depending upon that no other abnormal observations can be seen. ECG changes in older persons may be "normal" in the sense that they occur often, but they may still be of pathological importance. The prognostic value may be great. However, this should be studied further in longitudinal investigations.

PART V

A METHOD FOR PREDICTION OF AEROBIC WORK CAPACITY FOR FEMALES AND MALES OF DIFFERENT AGES

Introduction

For many purposes, a good method is needed for prediction of the aerobic work capacity, that is the maximal oxygen uptake, from a submaximal work test. In order to be generally applied in clinical medicine, industry and in testing of athletes, such a prediction ought to be made using only pulse rate and work load. In 1954 P.-O. Åstrand and Ryhming presented a nomogram for prediction of the aerobic work capacity for healthy individuals 18—30 years old by using this simple method. This prediction could be made with a standard deviation of less than $\pm$ 10 per cent.

The pre-requisites for the use of this procedure are 1) that the pulse rate during submaximal work increases approximately rectilinearly with the oxygen uptake, 2) that submaximal pulse rates not lower than 125 beats/min are used for the prediction and 3) that the pulse rate of the subject can reach a maximal value of ca. 195 beats per min (S.D. = $\pm$ 10) when cycling or walking.

Since older persons do not generally reach such a high maximal pulse rate of ca. 195 beats/min, at least not when cycling on the bicycle ergometer (I. Åstrand, 1958 a; I. Åstrand, P.-O. Åstrand and Rodahl, 1959; part I, p. 20) or when running on the treadmill (Robinson, 1938; Dill, Horvath and Craig, 1958), the question arises whether or not this nomogram can be applied by introducing a factor which corrects for the influence of age. In the original report by P.-O. Åstrand and Ryhming (1954) it was emphasized that "the nomogram is based on results from experiments with healthy subjects 18—30 years of age. We do not know its validity when testing younger or older people . . .".

Results of studies on older people are now available, and an analysis of these results is given in the present part of the study.

In 1958 Asmussen and Hemmingsen utilized some of the data presented here and gave a curve and a formula by which the aerobic work capacity could be estimated from submaximal loads.

Material

Determinations of oxygen uptake and heart rate at submaximal and maximal work for physically active female and male subjects were used as the basis

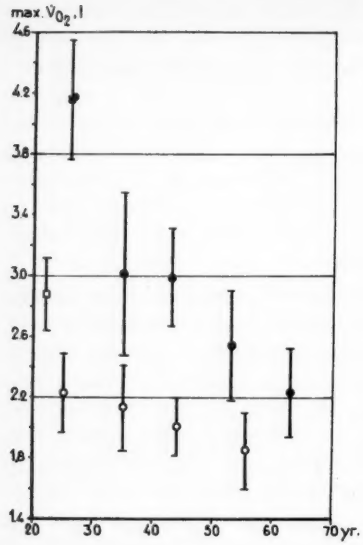

Fig. V: 1. Average maximal oxygen uptake ($\dot{V}O_2$, l) in relation to age for the various age groups of the whole material (76 females, unfilled dots and 129 males, filled dots). Squares = physical education students. $\overline{\underline{\circ}}$, $\overline{\underline{\bullet}}$ = mean value $\pm$ 1 $\times$ S.D.

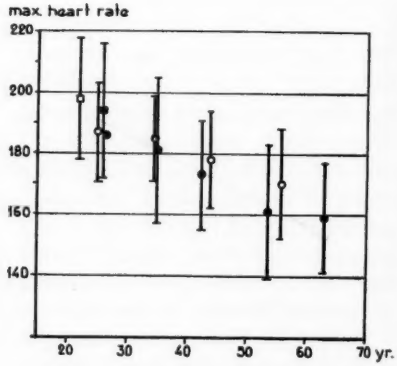

Fig. V: 2. Average maximal heart rate in relation to age for the various age groups of the whole material (76 females, unfilled dots and 129 males, filled dots). Squares = physical education students. $\overline{\underline{\circ}}$, $\overline{\underline{\bullet}}$ = mean value $\pm$ 2 $\times$ S.D.

TABLE V: I. *Number of subjects in the different materials and in various age groups*

	20–29	30–39	40–49	50–59	60–69	total n of subj.
female subjects						
(I) I. Å-D part I, p. 11	8	12	8	16		44
(V) P.-O. Å-D & R-G (1954)	32	—	—	—		32
total n of subjects	40	12	8	16		76
male subjects						
(II) I. Å-D (1958 a)	—	—	—	58	4	62
(III) I. Å-D *et al.* (1959)	—	—	—	5	4	9
(IV) unpubl. material of physical training	4	13	9	3	—	29
(V) P.-O. Å-D & R-G (1954)	24	5	—	—	—	29
total n of subjects	28	18	9	66	8	129

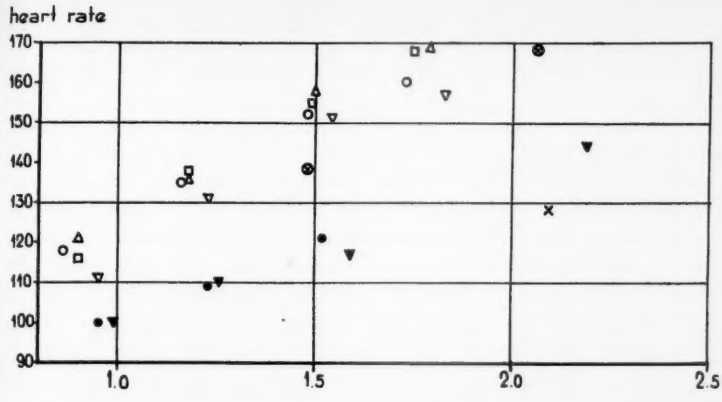

Fig. V: 3. Average submaximal heart rate in relation to oxygen uptake ($\dot{V}_{O_2}$, l) for the various age groups. Unfilled dots = females; o = 20—29; □ = 30—39; △ = 40—49; ▽ = 50—65 years old; ⊗ = physical education students. At 300—600 kpm/min (ca. 0.9—1.5 $\dot{V}_{O_2}$, l) 44 housewives, at 750 kpm/min (ca. 1.8 $\dot{V}_{O_2}$, l) 25. At 600 and 900 kpm/min (ca. 2.1 $\dot{V}_{O_2}$, l) 32 students. Filled dots = males. ● = 27—45; ▼ = 50—68 years old; × = physical education students. At 300 kpm/min 25 subjects, at 450 kpm/min 14, at 600 kpm/min 67 subjects and at 900 kpm/min 18 older subjects and 29 students. Note the small difference in heart rate at a certain work load for the different ages of the same sex if the well-trained students are not considered.

for the calculations which are presented below. The subjects consisted of (I) housewives 20—65 years old (for details see part I, p. 11), (II) draymen 50—64 years old (I. ÅSTRAND, 1958 a), (III) males 56—68 years old who were all members of a health club in Philadelphia, U. S. A. (I. ÅSTRAND, P.-O. ÅSTRAND and RODAHL, 1959) and (IV) males 27—45 years old who participated in a physical training program (moderate training for 5—6 weeks). The determinations made after the training period were used (previously unpublished results from Lankenau Hospital, Philadelphia and this department). The subjects in whom submaximal heart rates between 125 and 170 were not measured, for one reason or another, were excluded from the original materials. Thus, the actual material used consisted of 44 female and 100 male subjects. Twenty-nine male and thirty-two female students of the original nomogram material (V) were also included, making in total 205 subjects. The whole material was divided into different age groups according to Table V: I. Data from the whole material is summarized in Table V: II and Fig. V: 1, 2 and 3.

TABLE V: II. *Body weight and height and various data obtained during cycling from the whole material used for calculating the correction factor for age*

age group, yr	number of subjects	weight kg	height cm	max. $\dot{V}O_2$, l STPD	max. $\dot{V}O_2$, ml/kg STPD	max. $\dot{V}_E$, l BTPS	max. $\dot{V}_E/\dot{V}O_2$, l	max. lact. conc. mg/100 ml	max. heart rate
♀ 20–29	8	56.2 ± 2.15	166 ± 1.9	2.23 ± 0.09	39.9 ± 1.66	76.2 ± 5.71	34.1 ± 2.10	121 ± 6.8	187 ± 3.4
(25.0)		6.1	5.3	0.26	4.7	16.2	6.0	19	10
30–39	12	57.5 ± 1.93	165 ± 1.5	2.13 ± 0.08	37.3 ± 1.51	75.0 ± 4.40	35.2 ± 1.64	97 ± 4.6	185 ± 2.0
(34.7)		6.7	5.1	0.28	5.2	15.3	5.7	16	7
40–49	8	61.9 ± 1.51	164 ± 2.0	2.01 ± 0.07	32.5 ± 0.96	64.4 ± 4.89	31.8 ± 1.64	86 ± 6.8	178 ± 3.0
(43.9)		4.3	5.7	0.19	2.7	13.8	4.7	19	8
50–65	16	65.4 ± 2.21	160 ± 0.7	1.85 ± 0.06	28.4 ± 0.68	69.5 ± 1.26	33.1 ± 1.00	78 ± 3.3	170 ± 2.1
(55.6)		8.8	2.8	0.25	2.7	5.1	4.0	13	9
20–25	32	59.7 ± 0.93	166 ± 1.0	2.88 ± 0.04	48.4 ± 0.49	91.4 ± 1.91	[1]32.3 ± 0.5	104 ± 3.4	199 ± 1.8
(21.7)		5.3	5.6	0.24	2.8	10.8	2.8	19	10
P.-O. Å-D									
♂ 20–29	4	80.6	180	4.19	52.2	133.3	31.8	147	186
(26.5)									
30–39	13	76.3 ± 2.61	178 ± 1.9	3.01 ± 0.15	39.8 ± 2.02	104.9 ± 6.35	34.6 ± 1.66	120 ± 5.9	181 ± 3.5
(34.8)		9.4	6.4	0.54	7.3	22.9	6.0	21	12
40–49	9	76.4 ±2 .50	178 ± 2.0	2.99 ± 0.11	39.2 ± 1.81	90.1 ± 8.29	33.8 ± 1.77	109 ± 5.5	173 ± 2.9
(42.6)		7.5	6.0	0.32	5.5	24.9	5.3	17	9
50–59	66	77.2 ± 1.22	175 ± 0.7	2.54 ± 0.05	33.1 ± 0.60	67.2 ± 1.60	26.9 ± 0.57	61 ± 2.0	161 ± 1.3
(53.3)		9.9	5.8	0.36	4.9	13.0	4.6	16	11
60–69	8	71.8 ± 2.74	171 ± 1.8	2.23 ± 0.11	31.4 ± 1.87	79.8 ± 7.21	33.1 ± 2.04	76 ± 7.3	159 ± 3.1
(62.9)		7.8	5.0	0.29	5.3	20.4	5.8	21	9
20–33	29	71.2 ± 1.20	177 ± 1.1	4.16 ± 0.07	58.6 ± 0.83	121.9 ± 3.02	[1]29.4 ± 0.7	112 ± 3.9	195 ± 2.0
(25.8)		6.4	6.1	0.39	4.5	16.3	3.0	20	11
P.-O. Å-D									

[1] These values originate from the material of 31 female and 21 male subjects of P.-O. Å-D (1952, p. 75).

Methods

All results refer to cycling on the KROGH or V. DÖBELN (1954) bicycle ergometer. The work was performed on at least 2 days with light and heavy loads each day. On the last experimental day the subjects attempted to reach their maximal levels with regard to oxygen uptake. The work period for each load was usually 5—10 min, but at the highest load, however, it was sometimes only 2—3 min, cf. part I, p. 14. The values used for oxygen uptake and heart rate refer to the last minutes of work on each load and are usually mean values obtained either from determinations on two or more occasions, or from two or more successive determinations on the same occasion. An exception to this are the determinations of oxygen uptake made at maximal work, whereby the highest value was used if it differed from the other determinations by more than 0.08 l/min (see part I, p. 14). For further information concerning the methods see the different publications from which the material is taken. In order to objectively establish the degree of strain, the blood lactate concentration was determined. At maximal work the average was, for the different materials, (I) about 90, (II) 60, (III) 85, (IV) 111 and (V) 108 mg per 100 ml. These values indicate that the subjects worked at or close to their absolute maximum for this type of work during at least 2 min. With regard to the degree of strain at maximal work in older individuals, see part I, p. 12.

Adjustment of the nomogram and its usefulness at lower and higher loads.

When the nomogram was constructed a mechanical efficiency of about 23 per cent for all loads was assumed. From this nomogram an estimation of oxygen uptake from work load could be made. This was justified for the work loads used according to the results of P.-O. ÅSTRAND and RYHMING, 1954. Since the mechanical efficiency is considerably lower at lower loads, for example at 300 and 450 kpm/min, than at 600 and 900 (see part II, p. 29) the error becomes relatively large when using the lower loads if this is not taken into account. The use of lower loads is necessary, especially for older individuals, and therefore the nomogram was adjusted on this point. The results given in Table II: II, p. 29, were used for making this adjustment. Furthermore, since there is a difference in oxygen uptake at a certain work load between females and males, separate scales for the two sexes were set up (see Fig. V: 4). (However, the net mechanical efficiency is the same.) The small difference in oxygen uptake which was noted between younger and older subjects at a certain work load, on the other hand, did not justify separate scales for the two groups. Instead, a mean value for all age groups was used.

When the nomogram was constructed it was found that a better agreement between measured and predicted maximal oxygen uptake was obtained if the calculations were based upon the pulse rates at relatively high work loads. Therefore, it was recommended that only pulse rate values between 125 and

[1] These values originate from the material of 31 female and 21 male subjects of P.-O. ÅSTRAND (1952, p. 75).

170 beats/min should be used for the calculations. However, it may be of interest to know whether or not the calculation from a low and a high work load, with pulse rates within this range, provides identical values. Therefore, the female subjects from material (I), 36 all together, with both relatively low and high heart rates were selected for making this comparison. The heart rate for these subjects at the lower oxygen uptake was 135 ± 1.2 and at the higher 160 ± 1.2 beats/min. On the basis of these two different heart rate values and measured submaximal oxygen uptake values, the maximal oxygen uptake was predicted from the adjusted nomogram. The difference between these two maximums was, on the average, 0.060 ± 0.039 l/min. The pairs of values do not give significantly different results, $P = 0.2$. Correspondingly, male subjects were selected from the materials (II), (III) and (IV), making a total of 21 persons. The heart rates were 135 ± 1.8 and 156 ± 2.3 beats/min at the different oxygen uptake values. The corresponding difference for these subjects was 0.100 ± 0.061 l/min, ($P = 0.2$). Thus, there is a small systematical difference in the maximal oxygen uptake calculated from low and high work loads. (The difference is actually significant if the two materials are combined, $P < 0.001$.) However, the material is too small to justify a basic reconstruction of the nomogram.

In the present materials (I—V) there were, in about half of the cases, several submaximal values (heart rate between 125 and 170). In those cases a mean value for each individual was used in the calculations.

Correction factor for age when using the adjusted nomogram.

In the original nomogram material the standard deviation of the regression between measured and calculated maximal oxygen uptake was, for the females, ± 9.4 and for the males ± 6.7 per cent. The corresponding standard deviation for the 66 male subjects in the age group 50—59 years was ± 10 per cent. The correlation coefficient was 0.709 with a P-value of < 0.001. Accordingly, the nomogram may be applied on older subjects, if a factor for age is used.

The difference between the predicted and the measured maximal oxygen uptake in per cent of the measured value was calculated for each subject. If the predicted maximal oxygen uptake from the nomogram is called N and measured maximal oxygen uptake is called U, the formula for calculating the difference in per cent will be:

$$\text{difference} = \frac{(N - U) \times 100}{U}$$

The differences obtained in this way were plotted on diagrams as a function of age. The correlation coefficient for the individual deviation in per cent between calculated and measured oxygen uptake *and* age was, for the females, 0.722 ($P < 0.001$) and for the males 0.778 ($P < 0.001$). These predictions were based upon heart rate and measured oxygen uptake (A). When the

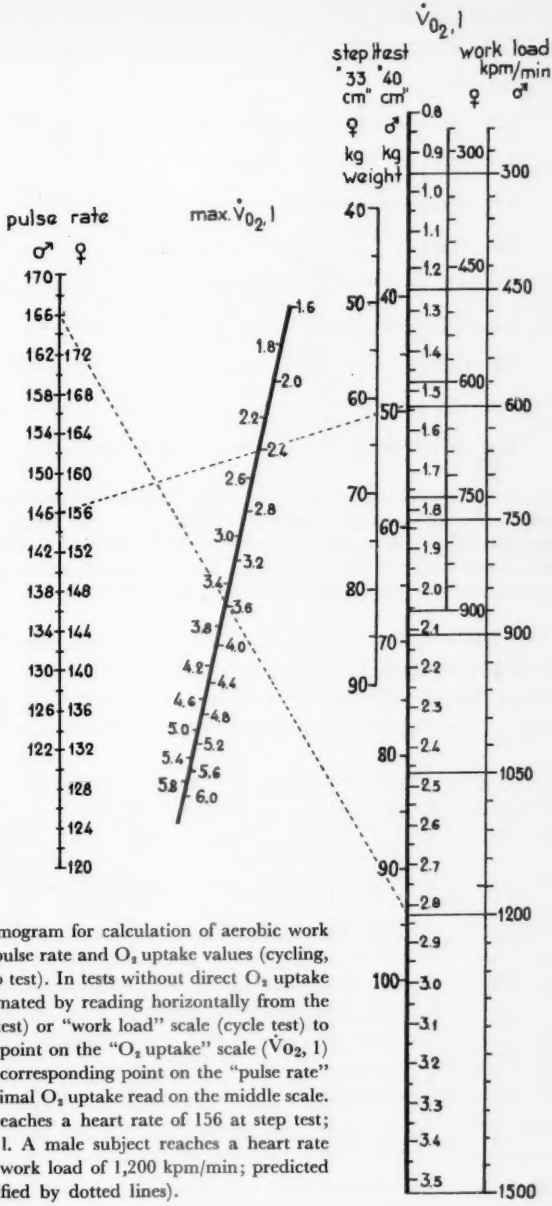

Fig. V: 4. The adjusted nomogram for calculation of aerobic work capacity from submaximal pulse rate and O_2 uptake values (cycling, running or walking and step test). In tests without direct O_2 uptake measurement it can be estimated by reading horizontally from the "body weight" scale (step test) or "work load" scale (cycle test) to the "O_2 uptake" scale. The point on the "O_2 uptake" scale ($\dot{V}O_2$, l) shall be connected with the corresponding point on the "pulse rate" scale and the predicted maximal O_2 uptake read on the middle scale. A female subject (61 kg) reaches a heart rate of 156 at step test; predicted max. $\dot{V}O_2$ = 2.4 l. A male subject reaches a heart rate of 166 at cycling test on a work load of 1,200 kpm/min; predicted max. $\dot{V}O_2$ = 3.6 l (exemplified by dotted lines).

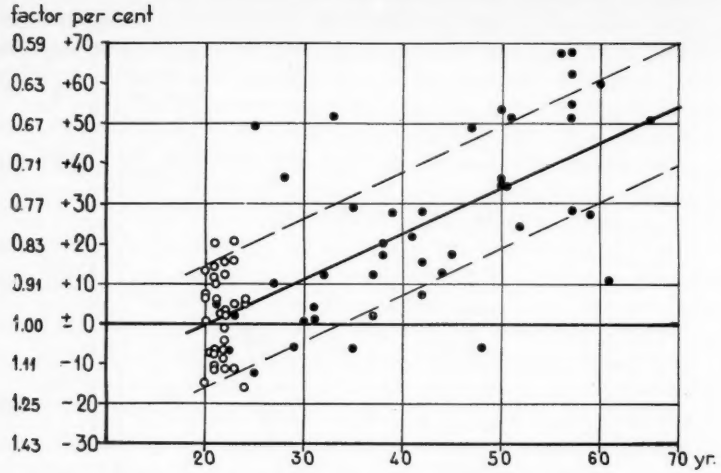

Fig. V: 5. Deviation in per cent (and corresponding correction factor) between predicted and measured maximal oxygen uptake in relation to age for female subjects. ● = housewives, material (I), o = students, material (V). The prediction is based upon submaximal O_2 uptake and heart rate (A). The dashed lines denote a deviation of $\pm$ 1 $\times$ S.D. from the regression line. For the statistical data see Table V: III.

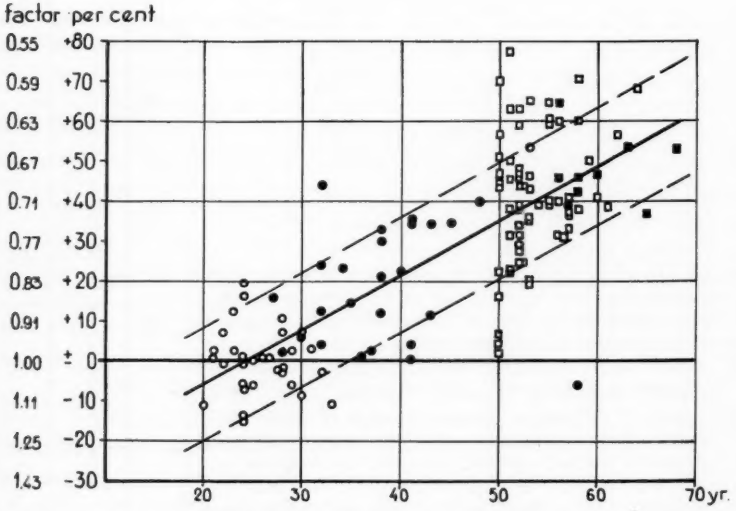

Fig. V: 6. For text see Fig. V: 5; male material. □ = material (II); ■ = material (III); ● = material (IV); o = students, material (V).

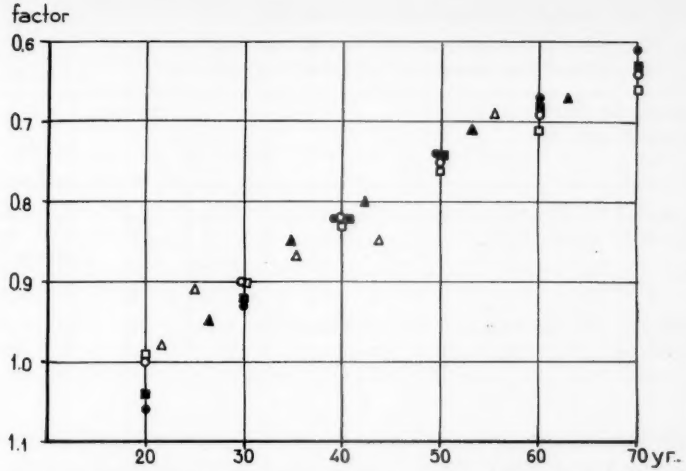

Fig. V: 7. Correction factor for the nomogram (Fig. V: 4) in relation to age. Unfilled dots = females, filled dots = males. ○, ● = factor from the regression equations A; □, ■ = from equations B in Table V: III. △, ▲ = ratio between measured and predicted (A) maximal oxygen uptake for the different age groups.

predictions were based upon heart rate and work load (B), the values were 0.653 ($P < 0.001$) and 0.718 ($P < 0.001$) respectively. The deviation from the regression line was in case (A) about 15 per cent and in case (B) about 16 per cent for both females and males. The results are summarized in Table V: III.

From the regression lines in Fig. V: 5 and 6, a factor for each age was calculated with which the estimated maximal oxygen uptake (A) should be multiplied to agree with the measured value. The formula for this calculation will be: factor $= \frac{U}{N}$. These factors were, for females 20 years old, 1.00; 30 years, 0.90; 40 years, 0.82; 50 years, 0.75; 60 years, 0.69 and 70 years, 0.64. The corresponding male factors were: 1.06, 0.93, 0.82, 0.74, 0.67 and 0.61. The factors based on work load and heart rate (B) were, on the whole, the same (see Fig. V: 7).

When calculating the regression lines, it was assumed that the deviation in per cent between predicted and measured values for maximal $\dot{V}o_2$ increased rectilinearly with increasing age. Therefore, the calculated correction factor should form a curved line with increasing age. In order to get some idea whether this was actually the case, the mean values for the individual correction factors for each age group were calculated. These factors are plotted together with the other in Fig. V: 7. A statistical analysis whether or not the

TABLE V: III. *Data from calculations for regression lines*

A. max. $\dot{V}O_2$ predicted from submaximal $\dot{V}O_2$ and heart rate
B. max. $\dot{V}O_2$ predicted from submaximal work load and heart rate

Deviation in per cent between predicted and measured max. $\dot{V}O_2$	sex	prediction	n
I. in relation to age. The prediction in based upon A or B. ($\bar{x}$ = age in years.)	♀	A	76
		B	76
	♂	A	129
		B	129
II. in relation to max. heart rate. The prediction is based upon A. ($\bar{x}$ = heart rate in beats/min.)	♀	A	76
	♂	A	129

different factors agree is impossible to make on this material which is comparatively small especially in the older ages.

The material, (I—IV), which primarily determine the slope of the curves in Fig. V: 5 and 6, consists of physically active persons in various ages. It can be considered as being quite homogeneous, but not as a normal material in the sense of an average material. However, the influence of age ought to appear relatively pure. Since the blood lactate concentration is definitely lower after maximal work for the oldest female subjects (see part I, p. 16) and for one of the oldest male groups (group II) than for the others, it is possible that their aerobic capacities were measured about 10 per cent too low (see I. ÅSTRAND, 1958 a). This means that the slopes of the curves in Fig. V: 5 and 6 should possibly have been somewhat less, and thus the factors for the various ages somewhat higher, since these groups dominate the older ages.

The mean value of the factor with which the estimated maximal oxygen uptake (A) should be multiplied to agree with the measured value is 0.72 for the 9 well-trained older subjects (III). Their blood lactate concentration after maximal work was on the average 85 mg per 100 ml. Average age was 60.2 years. The corresponding factor for the 21 subjects 55—64 years old from group (II) is 0.68, average age 57.7 years. The factor taken from the regression line (A) in Fig. V: 6 is 0.67 for the 60-year-olds. The differences between these factors are small. If somewhat higher values for the various factors than those taken from the regression lines are more probable, this means that the aerobic work capacity will be slightly under-estimated when using the presented values. (When selecting or advising people for manual labour or heavy muscular exercise it is, however, from a medical viewpoint, certainly better to under-estimate than to overestimate the aerobic work capacity.)

The correction factors given above for the nomogram applied on male and female individuals agree fairly well. Since the material used for calculating

$\bar{x} \pm \varepsilon_{\bar{x}}$	$\bar{y} \pm \varepsilon_{\bar{y}}$	regr. eq.	corr. coeff.	deviation from regr. line
33.6 ± 1.59	15.35 ± 2.51	$y = -22.95 + 1.14x$	0.722 ± 0.055	± 15.20
33.6 ± 1.59	14.65 ± 2.40	$y = -18.61 + 0.99x$	0.653 ± 0.066	± 15.92
44.3 ± 1.14	27.51 ± 2.01	$y = -33.15 + 1.37x$	0.778 ± 0.035	± 14.39
44.3 ± 1.14	27.08 ± 2.03	$y = -29.16 + 1.27x$	0.718 ± 0.043	± 16.10
187.1 ± 1.65	15.35 ± 2.51	$y = 247 - 1.24x$	− 0.817 ± 0.038	± 12.68
172.5 ± 1.58	27.51 ± 2.01	$y = 219 - 1.11x$	− 0.869 ± 0.022	± 11.35

the factor is relatively small, a common factor for both sexes is recommended. This factor is given in Table V: IV.

TABLE V: IV. *Nomogram correction factors recommended for women and men*

yr.	factor
25	1.00
35	0.87
45	0.78
55	0.71
65	0.65

Accuracy of prediction from the nomogram.

The aim of this study is, among other things, to evaluate how accurately the aerobic work capacity can be predicted by using a submaximal work test for older individuals. In order to find out whether there is the same degree of accuracy at low and at high loads, the values of the same two groups, as given on p. 50, were used. The predicted values were corrected for age, according to Fig. V: 5 and 6. The average difference between the individually estimated and measured values for maximal oxygen uptake for the first group of female subjects was 0.014 ± 0.063 (S.D. = ± 0.376) at a heart rate of 135 ± 1.2, and — 0.036 ± 0.042 (S.D. = ± 0.253) at a heart rate of 160 ± 1.2. For the second group of male subjects the corresponding values were — 0.029 ± 0.090 (S.D. = ± 0.411) at a heart rate of 135 ± 1.8, and — 0.109 ± 0.071 (S.D. = ± 0.323) at a heart rate of 156 ± 2.3. In the female material, but not in the male, the difference between the two S.D:s is significant, $0.05 > P > 0.02$. Thus, the accuracy seems to be somewhat higher when using relatively higher loads.

An important question is how much can be gained in accuracy when making repeated work tests on unexperienced subjects. In the original material (II) (all together 81 subjects) there were 11 subjects who had, at a certain work load (900 kpm/min), a lower oxygen uptake (> 0.08 l/min), heart rate and blood lactate concentration in the second test than in the first, thereby showing a higher mechanical efficiency. Besides this, there were 5 subjects who had only a considerably lower heart rate (> 14 beats/min) while other factors remained essentially unchanged at the second test. The average difference between predicted and measured oxygen uptake for the two test occasions was calculated. On the first occasion a significant difference was observed ($0.01 > P > 0.001$). However, the average difference for all 81 subjects was insignificant. In all of these cases, the results from the second work test were used in the calculations made in this study (cf. I. ÅSTRAND, 1958 a).

How accurately can the maximal oxygen uptake be predicted? Let us assume that one applies the method on a similar material, such as the present one, and arrives at a mean value of 3.0 l/min for maximal oxygen uptake. This estimation (A) is made from the nomogram in Fig. V: 4, with a correction factor for age from Table V: IV. From a S.D. of 0.45 l/min $\left(\frac{15 \cdot 3.0}{100}\right)$ one can expect that 2—3 persons out of 100 ($0.03 > P > 0.02$) with an estimated oxygen uptake of 3.0 l/min will actually have an oxygen uptake of less than 2.0 or more than 4.0 l/min. When the maximal oxygen uptake is estimated to 2.0 l/min, for example, one can accordingly expect that less than 1 person out of 1,000 ($0.001 > P > 0.0001$) will have an oxygen uptake of less than 1.0 or more than 3.0 l/min.

If the estimation is made from submaximal work load and heart rate (B), the P-values in the first example will be $0.04 > P > 0.03$, and in the second $0.01 > P > 0.001$. Therefore a small increase in the accuracy will be obtained when determining the actual oxygen uptake during submaximal work, naturally depending upon a varying mechanical efficiency. However, the aerobic work capacity can be estimated with a certain degree of accuracy, even though only work load and heart rate are measured.

However, it is obviously of primary importance, especially if only the work load is measured, that the bicycle ergometer used enables a correct reading of the given load. For that reason the ergometer should be so constructed that it is easy to calibrate; the calibration should stay constant and not change uncontrollably.

When applying the nomogram on data for submaximal oxygen uptake and heart rate (A), the standard deviation from the measured maximal oxygen uptake is less than $\pm$ 10 per cent for well-trained, younger persons, but about $\pm$ 15 per cent for the whole material. The reason for this difference is probably that the physical education students represent a selected group of subjects with a comparatively large oxygen uptake capacity. Moreover, they have had

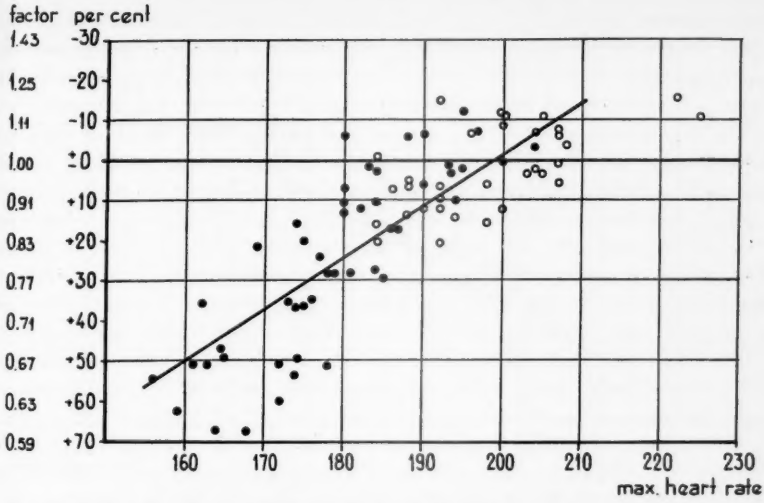

Fig. V: 8. Deviation in per cent (and corresponding correction factor) between predicted (A) and measured maximal oxygen uptake in relation to maximal heart rate for female subjects. ● = housewives, material (I), ○ = students, material (V). For statistical data see Table V: III.

more severe physical training than the other subjects. Physical training does not only increase the maximal oxygen uptake capacity, but also changes the individual slopes of the curves for heart rate and oxygen uptake. This means that the nomogram might have had a slightly different appearance if another original material had been used.

The correlation coefficient between the difference: $\frac{[N\,(A) - U] \times 100}{U}$ and the individual's maximal heart rate is -0.817 for the females and -0.869 for the males ($P < 0.001$) (see Table V: III, Fig. V: 8 and 9). This means that the standard error of estimate may be somewhat diminished if one knows the maximal heart rate of the individual. However, the difference between the two correlation coefficients (0.722 and -0.817 for females and 0.778 and -0.869 for males) was, in neither case, statistically significant (z-test according to FISHER, 1946, p. 197 ff). In this connection it is of interest to note that there is no difference between the S.D:s for maximal heart rate for the various age groups (see Table V: II).

Without an analysis of the subject's blood lactate concentration a prediction of a maximal heart rate higher than the average is impossible to make on the basis of a submaximal work test. If one requires that a certain minimal heart rate must be reached when using the nomogram, a low maximal heart rate may, however, be disclosed to a certain extent. This is particularly valid for

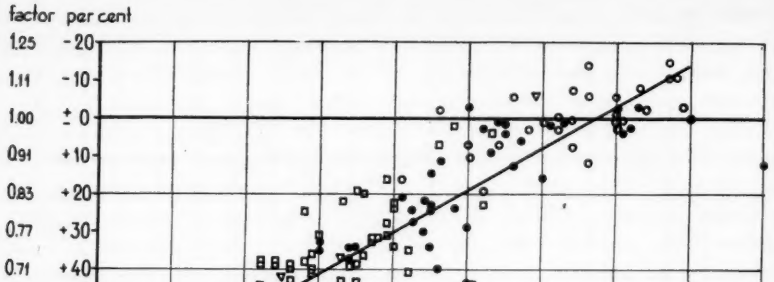

Fig. V: 9. For text see Fig. V: 8; male material. □ = material (II); ▽ = material (III); ● = material (IV); ○ = students, material (V).

the older ages. In most cases such a requirement involves cycling at several work loads. If cycling at several loads is always performed, those subjects who do not increase their heart rates despite increasing oxygen uptake values are automatically disclosed. Of course, the nomogram is not applicable in such cases.

For "healthy" individuals, a modification of the method may be considered. That is, after one or more submaximal tests have been performed, one further test is carried out in which the subject's maximal heart rate can be observed. The work load should be chosen so that the test can only be continued for about 2 min with maximal effort (see Methods, part I, p. 14).

Different types of test work for prediction of the aerobic work capacity.

When screening the aerobic work capacity by means of the nomogram, we have three different tests at our disposal, the cycle test, the step test, and walking or running on the treadmill. P.-O. Åstrand (1952, p. 88) showed that cycling and running gave identical results with regard to the aerobic work capacity for young individuals. Ryhming (1953) showed that the step test, as a submaximal test, with pulse rate counting during work could be substituted for the cycle test, at least for younger subjects. In the original report on the nomogram by these authors it was shown that cycling, running, and the step test could be used as submaximal tests for screening the aerobic work capacity of young subjects, if oxygen uptake was determined during the test or could be estimated.

All three of these types of test work have their advantages, provided they are carried out correctly. However, the S.D. of the oxygen uptake for cycling at a load of 300 kpm/min is lower (0.07 l or 7.7 per cent) than the S.D. of a corresponding oxygen uptake per kg body weight for walking (2.1 ml or 13.3 per cent) (cf. part I, p. 19 and part VI, p. 62). This means that a predicted value for maximal oxygen uptake at cycling is more accurate than at walking if the submaximal oxygen uptake is not measured. When cycling and step test are compared in a similar manner for young well-trained students one arrives at about the same accuracy for both tests (RYHMING, 1953).

When cycling, the mechanical efficiency is somewhat lower at lighter loads for older than for younger persons (see part II). However, the gross oxygen uptake is the same. Oxygen uptake per kg body weight on the treadmill is the same for adults of varying ages, (for references see P.-O. ÅSTRAND, 1956). Presumably this is also true for the step test. This means that even in older ages the tests should be interchangeable.

However, from the experience obtained on older persons at cycling and at walking on the treadmill, there is no doubt that the cycling test is preferable. The subjects complained quite often about dizziness while walking on the treadmill. Besides this, there is a great advantage in being able to reproduce exactly the same oxygen uptake for an individual. If the body weight changes this is much more time-consuming for walking or a step test than for cycling. Having the upper part of the body relatively relaxed and quiet, such as in cycling, also greatly facilitates the different measurements, the taking of blood samples and the ECG recordings.

It is obvious that all forms of extrapolation from submaximal work loads to a fixed heart rate, without regard to age, for the evaluation of the work capacity or capacity for oxygen uptake during cycling, walking or running or a step test may be misleading, depending upon different maximal heart rates in different ages. This is valid, regardless of whether one extrapolates to a heart rate of 170 (SJÖSTRAND, 1947; WAHLUND, 1948, p. 51 ff; BINK, 1959, p. 21 ff) continues the test until a heart rate of 180 (BALKE, 1954) or measures the so-called "Leistungspulsindex" (MÜLLER, 1950).

It should be strongly emphasized here that this method of measuring only the submaximal oxygen uptake or work load and heart rate will always be only an aid for a rough prediction of the aerobic work capacity. If one wishes to obtain more exact information, it is necessary to measure the aerobic work capacity directly.

Appendix.

Recently WYNDHAM *et al.* (1959) criticized the use of the above-mentioned nomogram. They found in a study on maximal heart rate and maximal oxygen uptake that the relationship between these two variables is rectilinear only up to a certain heart rate near the maximal. Thereafter, the curve approaches a horizontal asymptote in a diagram where heart rate is on the ordinate.

They drew the conclusion that, when using the nomogram, these results influence the predicted aerobic capacity so that it would be under-estimated by 0.32 ± 0.14 l/min. However, their criticism is not valid. It is not the premise of the nomogram that the heart rate is a rectilinear function of oxygen uptake throughout the range of values. It was constructed empirically from data on heart rate and oxygen uptake during submaximal work, and maximal oxygen uptake actually measured, in experiments where this oxygen uptake reached a well established level. It was not analysed whether or not the heart rate increased with the oxygen uptake at the upper level. The occurrence of individuals with a non-linear type of curve is probably the same in the material which was used when constructing as when applying the nomogram. This source of error was therefore included in the given standard error of less than $\pm$ 10 per cent.

It should be emphasized, however, that an asymptotic curve of the type described by WYNDHAM *et al.* has been observed in subjects when exposed to prolonged hypoxia (P.-O. ÅSTRAND and I. ÅSTRAND, 1958). As far as the author knows, the study by WYNDHAM *et al.* has been conducted at an altitude of 5,500 ft above sea level. Another adjustment to prolonged hypoxia consists of a decrease in maximal heart rate attained during work (CHRISTENSEN and FORBES, 1937; P.-O. ÅSTRAND and I. ÅSTRAND, 1958). It is noteworthy that the maximal heart rate presented by WYNDHAM *et al.* averages 178, which is rather low if their subjects were young. For this reason, among others, it was especially emphasized in the original report on the nomogram that the individual should be tested in a normal environment and, for instance, not exposed to hypoxia (P.-O. ÅSTRAND and RYHMING, 1954). It is not self-evident that the same norms for judging the aerobic work capacity can be used both at sea level and at high altitudes. This question is, among other things, of practical importance, due to the fact that many physiological departments are located at altitudes where slight hypoxia during work might prevail.

PART VI

A PILOT STUDY OF WORK ON A TREADMILL IN WOMEN 20—65 YEARS OLD

Introduction

Even if cycling may be preferred to walking as a test procedure for estimation of aerobic work capacity, it may be of interest to study an individual's reaction to a treadmill test, since the daily routine and most physically demanding jobs include walking. Besides this, walking may be more comfortable than cycling when performed for a longer time. It may also be motivated to compare walking with cycling since, for one reason or another, cycling must sometimes be replaced with this work test. Moreover, in many places, for example in the U. S. A., mainly treadmill tests are performed. An extensive study on walking was recently published in the U. S. A. by BALKE and WARE, 1959. The subject was reviewed in 1955 by PASSMORE and DURNIN.

Material and methods

Forty-two female subjects from the material presented in part I, p. 11 were tested on the treadmill with a fixed speed of 5 km/hr (3.1 miles/hr) without a slope (2 subjects 27 and 32 years old were not able to take part). Heart rate was determined each minute by an electrocardiographic pulse counter. Oxygen uptake, pulmonary ventilation and blood lactic acid concentration were determined in the same way as during cycling, see Methods, part I, p. 13. The work time was about 12 min. The values given in Table VI: I were calculated in the same way as for the cycling test.

This test was always made after all of the cycling tests were finished (see part I, p. 11). It was considerably more difficult to carry out than the cycling test, since many subjects complained about dizziness and felt unsafe and tense. For this reason, all the subjects had a chance to try out the treadmill on a day before the actual measurements were taken, in order to become more familiar with the procedure.

Results

The averages for oxygen uptake, heart rate, pulmonary ventilation and blood lactate concentration for the different age groups are presented in Table VI: I. Oxygen uptake was higher in the two older age groups (about 1.05 l/min) as compared to the two younger (about 0.87 l/min). However, this difference was evened out when considering the body weight. Oxygen uptake per kg

TABLE VI: I. *Mean values ± standard errors of the means and S. D. are given for oxygen uptake, heart rate, blood lactate concentration and pulmonary ventilation during walking with a speed of 5 km/hr for the different age groups of female subjects. For body weight see Table I: I. p. 12*

age group, yr.	n	$\dot{V}O_2$, l STPD	$\dot{V}O_2$, ml per kg weight STPD	heart rate	lact. conc. mg per 100 ml	$\dot{V}_E$, l BTPS
20–29	7	0.85 ± 0.03 0.09	15.2 ± 0.38 1.0	111 ± 2.8 7.5	15 ± 1.2 3.2	20.8 ± 0.68 1.8
30–39	11	0.89 ± 0.05 0.15	15.4 ± 0.49 1.6	112 ± 3.3 10.8	15 ± 1.1 3.7	22.9 ± 0.97 3.2
40–49	8	1.08 ± 0.07 0.19	17.5 ± 1.07 3.0	117 ± 4.3 12.1	15 ± 0.8 2.3	27.4 ± 1.42 4.0
50–65	16	1.01 ± 0.04 0.15	15.5 ± 0.48 1.9	108 ± 1.2 4.8	13 ± 0.8 3.0	24.9 ± 0.89 3.6

body weight was, for all subjects, on the average 15.8 ± 0.33 ml (range 13.4—21.6); heart rate 111 ± 1.4; pulmonary ventilation 24.2 ± 0.60 l and lactic acid concentration 14 ± 0.5 mg per 100 ml.

The oxygen uptake averaged 0.96 l/min. The maximal oxygen uptake for the same subjects was 2.02 l/min. This means that they, on an average, used 50 per cent of their aerobic capacities (somewhat more for the oldest, less for the youngest subjects). Therefore, the test seemed suitable for prolonged work.

The oxygen uptake in this study is of the same size as in earlier ones, for ref. see PASSMORE and DURNIN, 1955. These authors gave an equation for the relationship between energy expenditure and speed (3—6.5 km/hr) with a body weight between 60 and 75 kg: $C = 0.8\ V + 0.5$; where C = energy expenditure in Cal/min and V = speed in km/hr. According to that formula the energy expenditure for the present material should be about: $0.8 \times 5 + .0.5 = 4.5$ Cal/min, which is about 0.92 l/min in oxygen uptake. The coefficient of variation in $\dot{V}o_2$/kg of individuals walking at constant speed is about 15 per cent, according to MAHADEVA, PASSMORE and WOOLF, (1953). This figure is of about the same size in the present material.

Discussion

It is important to observe that the same load is usually placed on all persons independent of body weight when cycling, while when walking a certain work involves differing loads for various subjects due to differences in body weight. At walking, running or a step test greater amounts of energy are required for subjects with higher body weights provided that the mechanical efficiency is the same. This is clearly evident from Table VI: I where the oxygen uptake is higher in the two oldest age groups as compared to the two youngest. From the equalizing brought about by a recalculation to $\dot{V}o_2$ ml/kg it is evident

that this difference depends upon a difference in body weight (cf. RYHMING, 1953).

If walking on the treadmill is to be used alternately with the cycling test, one pre-requisite is that the relationships between heart rate, pulmonary ventilation and blood lactate concentration on the one hand and oxygen uptake on the other are essentially the same in both types of tests. If this is the case, the same procedure may be used when estimating the aerobic capacity (see part V). In this material, the oxygen uptake when walking with a speed of 5 km/hr was, on an average, 0.96 ± 0.03 l/min at a heart rate of 111 ± 1.4 and a pulmonary ventilation of 24.2 ± 0.60 l/min. The average blood lactate concentration was 14 ± 0.5 mg per 100 ml. The average body weight was 60.9 ± 1.20 kg. This means that this load corresponds quite well to a load of 300 kpm/min; the corresponding values for oxygen uptake, heart rate, pulmonary ventilation and blood lactate concentration were 0.91 ± 0.01 l/min, 115 ± 2.2 beats/min, 22.9 ± 0.54 l/min and 18 ± 0.7 mg per 100 ml.

PART VII

PHYSIOLOGICAL EFFECTS OF PROLONGED MUSCULAR WORK FOR ONE HOUR AND FOR ONE DAY

Introduction

It has been shown that there is a close agreement between the results obtained in the laboratory concerning aerobic capacity and the performances in endurance events in sport, *e. g.*, skiing and track events (P.-O. ÅSTRAND, 1954; 1955). We do not know for certain whether or not the agreement is as good when comparing with performance in daily heavy work. However, a certain oxygen uptake gives about the same heart rate with work on the bicycle ergometer as in heavy manual labour which engages great muscular groups (LUNDGREN, 1946, p. 115; ZOTTERMAN *et al.*, 1948, p. 62; CHRISTENSEN, 1955; P.-O. ÅSTRAND, 1956). Thus, such a job can be fairly well reproduced, with regard to the load on the circulation and respiration, by work on a bicycle ergometer or on a treadmill.

The heaviest types of continuous jobs, such as for instance forest work, probably demand about 50 per cent of the individual's aerobic capacity. In literature it has been pointed out that the 50 per cent level should not be exceeded in daily work (BRODY, 1945, p. 906; P.-O. ÅSTRAND, 1952, p. 148; CHRISTENSEN, 1955) in order to avoid excessive fatigue. However, this hypothesis has been tested fairly little experimentally. Investigations on continuous work for one hour on the bicycle ergometer, which required the mentioned 50 per cent of the subject's aerobic capacity, were made in 1959 by I. ÅSTRAND, P.-O. ÅSTRAND and RODAHL. Only four older male subjects performed these work tests. All of them could perform the work for one hour without an increase in oxygen uptake, heart rate, blood lactate concentration and pulmonary ventilation from about the 5th min.

However, in order to be able to state with certainty anything about the nature of such a work a greater material is necessary, especially with subjects of different capacities for oxygen uptake. Besides this, it is not known whether a work which can be performed for one hour without "fatigue symptoms" can also be performed for a whole work day. In order to further elucidate these questions the following experiments were made.

One hour's work test.

Material

For the 1 hour work tests 18 female subjects 40—65 years old were chosen at random from a group of 24 subjects. These subjects are described more in

TABLE VII: I. *Mean values ± standard errors of the means and S. D. for oxygen uptake, heart rate, blood lactate concentration and pulmonary ventilation of 18 female subjects 40—65 years old. They walked continuously for about 1 hour with a speed of 5 km/hr and their values at the beginning and at the end of the work period are given*

time for the measurements	n	$\dot{V}_{O_2}$, l STPD	heart rate	lact. conc. mg per 100 ml	$\dot{V}_E$, l BTPS
at the 5^{th}—12^{th} min	18	1.04 ± 0.04	112 ± 2.3	14 ± 0.7	26.0 ± 0.95
		0.15	10	2.9	4.0
at the 50^{th}—60^{th} min....	18	0.98 ± 0.04	108 ± 3.3	9 ± 0.5	23.2 ± 0.79
		0.14	14	2.0	3.3

detail in part I, p. 11. Their average aerobic capacity measured during the cycling experiments was 1.99 ± 0.04 l/min.

Methods

All experiments were made in the morning at least 1 hour after a light breakfast. The subjects walked continuously for 1 hour on the treadmill at a speed of 5 km/hr (3.1 miles/hr) without a slope. Room temperature was kept at 18—20° C. All of them had practiced walking on the treadmill twice before on different days (see part VI), and the oxygen uptake was predicted to be about 50 per cent of their aerobic capacities.

Heart rate was determined with an electrocardiographic pulse counter every other minute. Oxygen uptake, pulmonary ventilation and blood lactate concentration were determined according to the methods described in part I, p. 13. In the beginning (5—12 min) and at the end of the hour (50—60 min) double determinations were made, and in between single determinations were made every 10 min (7 different determinations in all). Rectal temperature was taken immediately after work with a fever thermometer, and urine was tested for the presence of albumin. The subjects were asked to describe their subjective feelings during the work.

Results

The individual mean values of the double determinations in the beginning and at the end of the hour for oxygen uptake, pulmonary ventilation and blood lactate concentration, and the corresponding values for heart rate, are the basis for the average values presented in Table VII: I. From these it is evident that all four factors were of the same order of size in the beginning and at the end of the period. There is a tendency for the values to be *lower* at the end

than at the beginning, but the variations are not significant. Thus, oxygen uptake is at these times 1.04 and 0.98 l/min respectively. The decrease in heart rate with 4 beats/min and in pulmonary ventilation with 2.8 l/min approximately corresponds to the decrease in oxygen uptake. During the work the body weight decreased with roughly 0.3 kg (see later). A change in body weight of 1 kg corresponds to a decrease in $\dot{V}o_2$ of about 0.02 l according to calculations from Table VI: I, p. 62. Accordingly the loss in weight is too small to cause a decrease in the oxygen uptake of 0.06 l/min. The blood lactate concentration decreased from 14 to 9 mg per 100 ml. This common tendency is confirmed by the values obtained in between. On the average, the work was performed continually for 55 min and demanded 51.0 $\pm$ 1.7 per cent of the aerobic capacity (S.D. = $\pm$ 7.1). Body temperature after work was 37.6° C. No one complained about fatigue during the work; the only troublesome factor was dizziness (compare part VI, p. 61). One subject had a trace of albumin in the urine after work. Before work this test was negative.

Discussion

From the results it is evident that all of the 18 subjects performed 1 hour's work in a real steady state, when they used approximately 50 per cent of their aerobic capacities. If anything, oxygen uptake, heart rate and pulmonary ventilation decreased during the work hour. The blood lactate concentration was highest at the beginning of work, which is an expression for an anaerobic phase just at the beginning. All of the subjects performed the work without subjective symptoms of fatigue. One had a trace of albumin in the urine after work, which may be interpreted as an expression that the work was relatively heavy and influenced the renal circulation (cf. JUNDELL and FRIES, 1911).

The younger subjects described later used 50 per cent of their aerobic capacities at a higher heart rate than the older subjects, on the average 123 beats/min as compared with 110. For the four older men mentioned earlier (I. ÅSTRAND, P.-O. ÅSTRAND and RODAHL, 1959), the corresponding heart rate was on the average 105. This condition reflects the older subjects' lower maximal heart rate. If this lower maximal heart rate is not considered, the aerobic capacities of the 18 subjects, estimated from submaximal heart rate and oxygen uptake (see part V, p. 51), would be, on an average, 2.60 as compared with an actually measured value of only 1.99 l/min. If one had used 2.60 as a basis, the subjects should instead have walked on the treadmill with an oxygen uptake of 1.30 l/min, corresponding to 65 per cent of their actual aerobic capacities instead of 50 per cent. Hereby they would have reached an average heart rate of about 140 and a blood lactate concentration of about 35 mg per 100 ml (compare Fig. I: 6 and 8). It is doubtful whether they would be able to perform that work load for one hour or more in a real steady state.

Seven hours' work test.

Material

For the one day work tests two females (A: 35 and B: 27 years old) and 2 males (C: 30 and D: 24 years old) were used. They were "healthy" laboratory personnel and their measured aerobic capacities were 2.25, 2.73, 4.60 and 5.60 l/min respectively. Their body weights were 56.4, 59.7, 73.0 and 84.4 kg respectively.

Methods

The experiments started in the morning after a light breakfast. Before the work experiment a blood sample was taken for determining the rest values for blood lactate concentration and hematocrit. Body weight and temperature were measured. For methods, see later.

The four subjects alternately cycled on the ergometer and walked on the treadmill continuously for 50 min after which a 10 min rest was taken. A total of 5—15 min physically inactive time per hour corresponds fairly well to conditions in heavy manual occupations where hot climatic conditions do not exist, for example in timber cutting, manual handling of lumber in dock work, machine moulding in a foundry, assisting at a cold rolling mill and kiln work in a brick factory. These jobs have been studied during the past five years by the Division of Industrial Physiology at this department (LUNDGREN, personal communication). In the morning 3 such work periods of 50 min each were performed, and in the afternoon, after a lunch pause of 1 hour, 4 other periods were carried out. In each case, work load, speed and slope were chosen so that oxygen uptake corresponded to about 50 per cent of the individual's aerobic capacity. Thus, the female subject (A) with an aerobic capacity of 2.25 l/min cycled at a load of 450 kpm/min and walked with a speed of 6 km/hr (3.7 miles/hr) with a 1° slope, and the male (D) with 5.60 l/min cycled at a load of 1,200 kpm/min and walked with a speed of 7.5 km/hr (4.7 miles/hr) with a 2 1/2° slope. The subjects were asked to describe their subjective feelings during work.

Room temperature was kept between 17° and 19° C, and a small electric fan was placed in front of the subject to secure sweat evaporation.

Ordinary meals were eaten during the day, and extra calories and liquids were consumed *ad libitum*. In order to have a certain control over the fluid balance during the day, weight was measured (accuracy within 50 g) after each 50 min period, and the amounts of food and drink taken in plus the amount of urine and faeces given off were measured. The urine was tested for the presence of albumin. Besides this, blood samples were taken for the determination of hematocrit (see below). At the end of each 50 min period rectal temperature was measured with a fever thermometer.

Heart rate, oxygen uptake, pulmonary ventilation and blood lactate concentration were determined according to the methods given in the preceding

section. Heart rate was measured at intervals of about 2 min during the 7 periods. Determinations of the other functions were made in the beginning (5—10 min) and at the end (38—43 min) of each 50 min period. The first and the last determinations of the day plus the determinations immediately preceding and proceeding the lunch pause were double determinations, and those in between were all single. All together 18 determinations were made during the 7 hours. A blood sample for hematocrit determination was taken at the same time as the sample for lactic acid. Heparin was added as an anticoagulant. The 10-cm long capillary test tubes were centrifuged for 30 min with a speed of 3,000 revolutions/sec. The mean value of two determinations was used. The value was corrected for trapped plasma with a factor of 0.95 (for literature see v. PORAT, 1951, p. 29).

Results

At rest no abnormal values were observed. All four subjects performed the first hour's work in a real steady state.

The mean values of the 18 determinations for oxygen uptake for the four subjects A, B, C and D were 1.15 ± 0.01, 1.34 ± 0.01, 2.45 ± 0.02 and 2.74 ± 0.03 l/min respectively, which means that on the average 51.1, 49.1, 53.3 and 48.9 per cent of their aerobic capacities were used. All values for subject C for heart rate, oxygen uptake, respiratory quotient, blood lactate concentration, hematocrit, rectal temperature and body weight during the 7 work periods are given in Fig. VII: 1. The values for the other subjects showed the same tendencies.

The values for oxygen uptake were somewhat higher (ca. 8 per cent) during the afternoon than during the morning for A, B and C. This was also valid for the heart rates in all subjects. These increased with 9—17 beats/min (see Table VII: II). On an average the respiratory quotient decreased from 0.87 to 0.77. The blood lactate concentration was about 25—30 mg per 100 ml in the beginning, the first value being the highest. After one hour the value was about 16 mg per 100 ml and during the last period 10 mg per 100 ml. The body temperature was approximately 38.0° C for all subjects (see Table VII: II).

Body weight decreased for A—D with 0.10, 0.75, 1.95 and 1.50 kg, corresponding to 0.2, 1.3, 2.7 and 1.8 per cent of their body weights. The weight losses, depending upon the oxygen-carbon dioxide shift, were about 75, 95, 170 and 190 g for the 7 hours. In these calculations the respiratory quotient was averaged to 0.82. The hematocrit values were unchanged for all subjects during the 7 hours; for A it was about 0.38, B about 0.37, C about 0.48 and D about 0.43. The sweat rate was calculated to correspond approximately to the weight loss per unit of time corrected for the intake of food and drink and for weight loss in urine and faeces (1 g urine = ca. 1 cc). A mean value

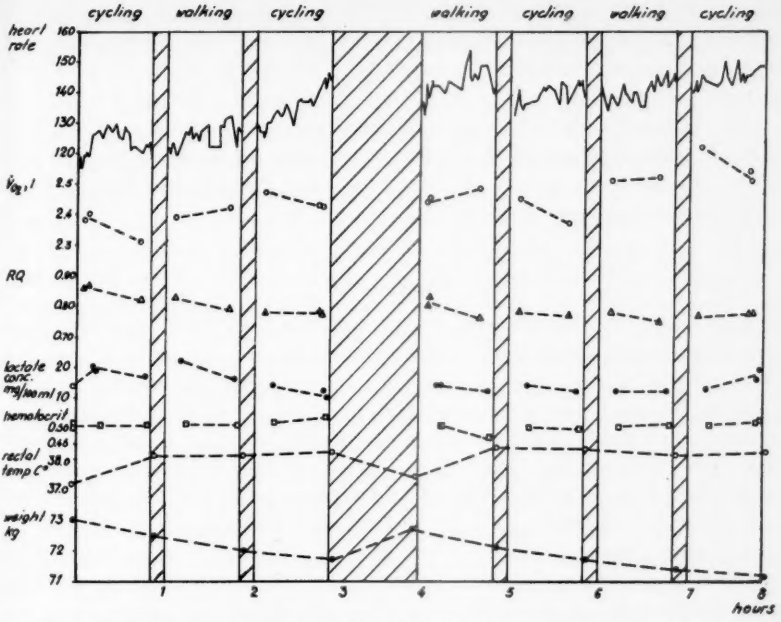

Fig. VII: 1. Different measurements on subject C during the whole experiment day, consisting of 7 work periods of 50 min each. The striped columns = rest periods.

for the seven 50 min periods was calculated for each subject. These were 250, 340, 650 and 750 cc/hr.

The total calorie conversion during work was calculated from the mean values for oxygen uptake and respiratory quotient. For the 4 subjects these

TABLE VII: II. *Mean values of oxygen uptake and rectal temperature and mean values ± standard errors of the means of heart rate for the four subjects A, B (female), C and D (male). They walked or cycled continuously during 7 periods of 50 min each; the values from the first and the last 2 periods are given. The work load corresponded to about 50 per cent of their aerobic capacities*

		n	subject A	subject B	subject C	subject D
first 2 periods....	heart rate	> 18	119 ± 0.7	134 ± 0.6	126 ± 0.6	115 ± 0.7
	$\dot{V}_{O_2}$, l	5	1.07	1.30	2.38	2.76
	body temp. C°	2	37.8	38.2	38.1	38.0
last 2 periods....	heart rate	> 27	129 ± 0.6	143 ± 0.8	143 ± 0.6	124 ± 0.6
	$\dot{V}_{O_2}$, l	5	1.19	1.37	2.55	2.76
	body temp. C°	2	38.0	38.1	38.2	38.3

were 2,000, 2,300, 4,250 and 4,750 Cal. The total expenditure during the day was calculated from 6 hours' effective work, 8 hours' basal metabolism and 10 hours with an output of 2.0 (A, B) and 2.5 (C, D) Cal/min. Thus, the 24-hour expenditure was for A—D about 3,700, 4,000, 6,400, and 6,900 Cal.

None of the 4 subjects had any subjective symptoms of fatigue after 1 hour of work; after 7 hours the 2 female subjects had aches in the muscles and joints, and one male subject (C) was very hungry and tired. None of them had albumin in the urine after work.

Discussion

It was shown by CHRISTENSEN (1931) and NIELSEN (1938) that the body temperature during continuous work adjusts itself at a certain level which is in proportion to the energy output. The latter author also showed that the body temperature during work is independent of the environmental climate within certain limits. The first actual practical application of this in industry was made by LUNDGREN (1946, p. 105 ff), who showed that measurement of body temperature is an excellent method for calculating the heaviness of work in forestry. This method was used by BERGGREN and CHRISTENSEN (1950) for classifying various sports from an energy output viewpoint. LUNDGREN (1946, p. 105 ff) reported that all of his six subjects reached approximately the same body temperature, 38.0° C, at timber felling and firewood cutting, and also at cycling with an oxygen uptake of about 2 l/min. However, individual variations existed. The author himself had a higher body temperature than the others at a certain oxygen uptake and thought that this depended upon a poorer physical condition.

All the 4 subjects A—D had approximately the same body temperature, 38.0° C, during all the work periods with a tendency to slightly increase towards the end. Their average oxygen uptake values were 1.15, 1.34, 2.45 and 2.74 l/min respectively. The results from the 4 subjects most closely indicate that it is not the absolute but the relative energy output which is the deciding factor for the body temperature level during exercise. According to this hypothesis, a 50 per cent use of the aerobic capacity should, therefore, result in a body temperature of about 38.0° C. The results of CHRISTENSEN (1931), NIELSEN (1938), LUNDGREN (1946, p. 105 ff) and BERGGREN and CHRISTENSEN (1950) closely agree with this theory when the aerobic capacities of their subjects are estimated. The dehydration that occurred in the present study is probably the main cause of the slight increase in rectal temperature during the day.

It is difficult to explain why the 18 older subjects had a lower body temperature (37.6° C). The calorie production was sufficiently large (ca. 200 Cal.) to bring about a larger increase and the work times was sufficiently long. Possibly this may be due to a difference caused by ageing. The four older

male subjects previously discussed by I. ÅSTRAND, P.-O. ÅSTRAND and RODAHL (1959) did not reach 38.0° either, but only 37.7° C on an average.

The drop in the respiratory quotient from ca. 0.87 to ca. 0.77, which was obtained during the 7 hours of work, corresponds to a successive transfer to a comparatively greater fat combustion. It has been shown earlier (KROGH and LINDHARD, 1920; CHRISTENSEN and HANSEN, 1939) that a transfer from carbohydrate to fat combustion corresponds to a decrease in mechanical efficiency of 5—10 per cent. For further references see CHRISTENSEN (1958, p. 13 ff). An increase in oxygen uptake from 2.38 to 2.55 l/min for subject C corresponds to a decrease in mechanical efficiency from 23.5 to 22.3 per cent (5 per cent). The values for the caloric coefficients for oxygen suggested by CATHCART and CUTHBERTSON (1931) were used in these calculations. Subjects A and B had a similar decrease. Thus, the present results closely agree with those reported earlier. However, it should be mentioned that in these cases it is possible that an increase in oxygen uptake occurred, since the coordination might have been slightly worse at the end of the work due to fatigue.

As can be seen in the individual diagrams on the relationship between oxygen uptake and heart rate, the increase in oxygen uptake which was found for subjects A, B and C corresponds to an increase in heart rate of about 5 beats/min. (The average oxygen uptake for subject D did not increase.) Since the increase in heart rate is between 9 and 17 beats for subjects A—D, this increase must therefore partly be caused by other factors. The four subjects A—D, after 7 hours, had weight losses corresponding to 0.2, 1.3, 2.7 and 1.8 per cent of their body weights. These losses, to a large degree, are certainly dependent upon dehydration. Subject C, with 2.7 per cent loss, had the largest increase in heart rate, 17 beats/min.

In 1947 ADOLPH (p. 204) showed that a decrease in body weight with about 1.5 per cent caused by dehydration involves an increased load on the circulation, which can be seen by an increase of about 10 beats/min in the heart rate during work.

One curious observation is that the heart rate remained at a certain level during the two first work periods, increased during the third and then remained fairly constant (see Fig. VII: 1). For the 3 subjects B, C and D, who were greatly dehydrated, this phenomenon may be explained by the fact that during the first 2 work periods they did not drink or eat anything. Thereafter they consumed a certain amount which was, however, not sufficient to restore the body weight and to lower the heart rate to the initial level. However, this explanation does not hold true for subject A, who had the same heart rate curve as the others, but maintained the same weight during the 7 hours. Besides this, B and C had a tendency to increase their heart rates during each hour, and after a 10 min pause they began again at a lower level, see Fig. VII: 1. This is most obvious during the third period immediately before lunch and during the last two work periods. This increase in heart rate may

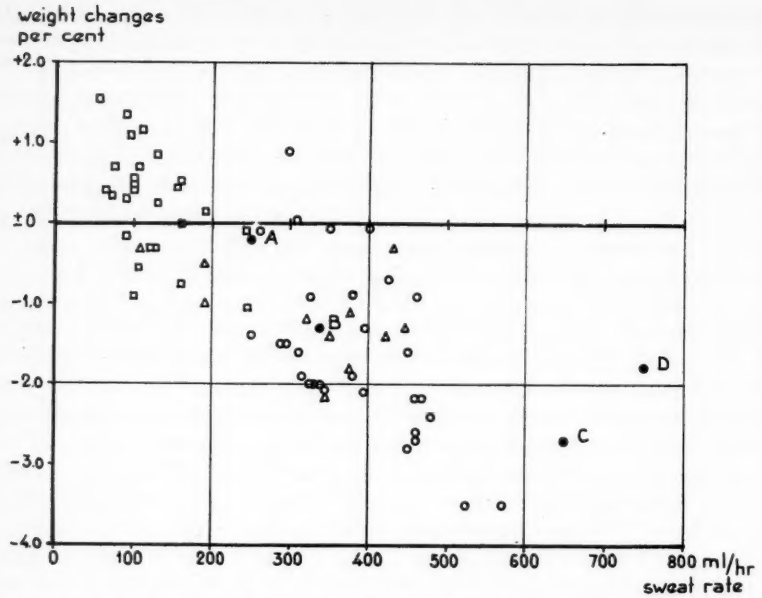

Fig. VII: 2. Weight change in per cent during a 7—8 hours' period in relation to sweat rate for kiln workers in a brick factory (o), tree planters (△), motor testers in an automobile factory (□) and for the present four subjects A—D (●).

be explained as an effect of dehydration, but might also be related to a depletion of the glycogen depot, according to unpublished results from this department.

The two male subjects reached their highest heart rates in the 4th period, *i. e.* after the lunch pause. This was probably caused by a distribution of a greater amount of blood to the splanchnic area in connection with the intake of a large lunch.

Dehydration was mainly caused by a high sweat rate due to a large caloric output. It should be noted that the use of body weight as a measure of dehydration is a more sensible method than the determination of hematocrit, which was constant during the 7 hours. The sweat rates for the 4 subjects A—D ranged from 250 to 750 cc/hr during the work, and the total caloric output for 24 hours from 3,700 to 6,900 Cal. In heavy occupations such sweat rates and caloric outputs are not uncommon. For the sake of comparison the weight losses of the four subjects are plotted in relation to sweat rate in Fig. VII: 2, which also shows this relationship for kiln workers in a brick factory, tree planters, and motor testers in an automobile factory. These investigations

were carried out by LUNDGREN, 1955—1959 (personal communication). Caloric expenditure of up to 6,000—7,000 Cal/24 hr are reported by, among others, LUNDGREN (1946, p. 19); ZOTTERMAN *et al.* (1948, p. 67 ff), and KARVONEN and TURPEINEN (1954). During the classic Vasa race, the marathon of cross-country skiing 85 km, the energy output for only the skiing period of 6—7 hours for the best ski-runners was calculated to a minimum of 7,000 Cal (HEDMAN, 1957). For persons engaged in heavy occupations, common experience has shown that heart rate increases during the day, LUNDGREN, 1959.

In order to find out whether or not a complete recovery will occur until the next day, it is necessary to repeat these experiments for several days in succession. However, under all circumstances, it is not probable that one from a social point of view would wish to recommend such a heavy daily load. Therefore, the conclusion is that "the 50 per cent level" certainly should be the upper limit for work of the mentioned type.

GENERAL SUMMARY[1]

Six earlier publications

RYHMING, IRMA, A modified Harvard step test for the evaluation of physical fitness. *Arbeitsphysiologie* 1953. *15.* 235—250.

A submaximal test for estimating the physical working capacity has been worked out and compared with a more complicated bicycle test. The testing procedure is a modification of the Harvard step test which in its original form is a maximal test. The pulse rate was counted during work.

The bench height was 40 cm for young males and 27 for the older ones and for the females 33 cm; 22.5 steps per min.

The average values for "step test 40 cm" and "bicycle test 900 kpm/min" for male subjects were: oxygen intake 2.11 $\pm$ 0.04 and 2.15 $\pm$ 0.02 l/min; pulse rate during work 130 $\pm$ 1.5 and 132 $\pm$ 1.9 beats/min respectively. The average values for "step test 33 cm" and "bicycle test 600 kpm/min" for female subjects were: oxygen intake 1.56 $\pm$ 0.03 and 1.48 $\pm$ 0.02 l/min; pulse rate during work 140 $\pm$ 1.6 and 138 $\pm$ 2.2 beats/min respectively. The mechanical efficiency did not vary with the body height or weight.

As the aerobic capacity for trained individuals without excessive fat is closely correlated to the body weight the light ones will be tested at a relatively higher intensity than the heavy ones using the bicycle test with a fixed load. In the step test the load varies with the body weight and all subjects will have to engage the same percentage of their aerobic capacity. To obtain the same result with the bicycle test, the load must be individually adapted.

Values are given whereby the aerobic capacity can be roughly estimated from the pulse rate during step test and bicycle test.

ÅSTRAND, P.-O. and IRMA RYHMING, A nomogram for calculation of aerobic capacity (physical fitness) from pulse rate during submaximal work. *J. appl. Physiol.* 1954. *7.* 218—221.

A nomogram is presented where an individual's maximal attainable oxygen intake (aerobic capacity) can be calculated from heart rate and oxygen intake (or work level) reached during a test with a submaximal rate of work. As test work a step test, treadmill test or cycle test can be chosen. It is suggested that the individual's aerobic capacity per kilogram body weight per minute will give a good measure of his physical fitness. *Values for healthy, well-trained men and women 20—30 years of age are presented.*

[1] In the following summary titles and the text printed in italics might give the reader the theme of the study.

ÅSTRAND, IRMA, The physical work capacity of workers 50—64 years old. *Acta physiol. scand.* 1958. *42.* 73—86.

Eighty-one of one hundred 50—64 years old transport workers for breweries in a district of Stockholm were examined with respect to physical work capacity. The subjects were tested on a bicycle ergometer at increasing work loads, the heaviest of which caused the subject to be exhausted after about 6 minutes work. The following conclusions could be drawn from the data obtained.

1) *The pulse reaction to a submaximal work load did not differ from that one of younger subjects. Mean heart rate at about 900 kpm/min was about 145 beats/min.*

2) Maximal work was reached at a lower work load than in younger subjects with the same pulse reaction to submaximal work.

3) *The heart rate at maximal work was about 160 beats per minute at an oxygen intake of about 2.5 litres per minute.*

4) *The physical work capacity of individuals of different age can not be estimated and compared only on the basis of the pulse reaction to submaximal work.*

ÅSTRAND, IRMA, Clinical and physiological studies of manual workers 50—64 years old at rest and during work. *Acta med. scand.* 1958. *162.* 155—164.

Eighty-one men employed as truck drivers for breweries in Stockholm were examined at rest and during work. *Twelve per cent had pathological or suspected pathological ECG recordings at rest. Nineteen per cent developed a pathological and 33 per cent a suspected pathological ECG during work.* Thirty-two per cent had high blood pressure at rest and 47 per cent were considered as overweight.

The vital capacity averaged 4.64 litres, the residual volume 1.99 litres or 30 per cent of the total capacity.

The ventilation per litre oxygen intake at submaximal work was about 4 litres higher than for younger people. The maximal pulmonary ventilation was, however, much lower.

The probable limiting factors for older people when performing muscular work are discussed. *None of the above-mentioned more or less pathological findings were found to be correlated with maximal oxygen intake or maximal heart rate. The reason for the decreased physical work capacity could not be explained.*

ÅSTRAND, P.-O. and IRMA ÅSTRAND, Heart rate during muscular work in man exposed to prolonged hypoxia. *J. appl. Physiol.* 1958. *13.* 75—80.

Heart rate was recorded on four subjects performing muscular work at sea level, during a 4-week sojourn at 14,250 feet altitude, during reacclimatization to sea level conditions and during acute exposure in an altitude chamber. *The heart rate of two* of these *subjects after acclimatization seemed to approach a relatively low ceiling at high work rates.* This probably limited their cardiac output and oxygen transport. *It was observed that an increase in oxygen supply* ($P_{I_{O_2}}$) *during heavy work in these subjects, however, promptly increased the heart rate well above this ceiling* (in one case from 138 to more than 160 beats/min within

15 seconds). This response was observed only in acclimatized subjects. After reacclimatization to sea level, when acute hypoxia in the altitude chamber was removed by switching to oxygen during work, heart rate invariably decreased.

ÅSTRAND, IRMA, P.-O. ÅSTRAND and K. RODAHL, Maximal heart rate during work in older men. *J. appl. Physiol.* 1959. *14.* 562—566.

Nine 56—68-year-old male subjects performed muscular work up to maximal loads on a bicycle ergometer while breathing both ambient air and oxygen. *Heart rate increased to an average maximum of 163/min.* The maximal O_2 intake averaged 2.24 l/min, and the blood lactic acid concentration 85 mg/100 ml. *In no case was the maximal heart rate higher when breathing O_2 than when breathing air.* This low maximal heart rate in older people probably limits the capacity for O_2 intake. Four subjects were able to work for about 1 hour without any sign of exhaustion on a work load requiring an O_2 consumption of about 50 per cent of their maximal aerobic work capacity.

Seven parts in the present publication

PART I, CAPACITY FOR OXYGEN UPTAKE AND RELATED FUNCTIONS DURING CYCLING IN WOMEN 20—65 YEARS OLD. p. 11—26.

Forty-four physically active female subjects 20—65 years old were examined on 3—7 different days when cycling at submaximal up to maximal loads. Heart rate, pulmonary ventilation and oxygen uptake were determined during work and blood lactate concentration was measured after each work load.

At submaximal loads about the same average values were reached by younger and older subjects. The S.D:s for heart rate and blood lactate concentration were large for both younger and older subjects.

At maximal work the 20—29-year-old subjects reached an average heart rate of 187 beats/min at an oxygen uptake of 2.23 l/min, the 50—65-year-old subjects 170 beats/min and 1.85 l/min respectively. The decrease in aerobic work capacity and maximal heart rate is discussed.

PART II, MECHANICAL EFFICIENCY OF YOUNG AND OLD PEOPLE AT LOW AND HIGH WORK LOADS DURING CYCLING. p. 27—32.

Female and male subjects 20—68 years of age performed principally aerobic work on a bicycle ergometer.

The measured oxygen uptake at a certain load was somewhat smaller for the younger than for the older subjects. Women had lower oxygen uptake than men at a fixed work load but calculated mechanical efficiency was identical.

At lower loads, for example at 300 kpm/min, the mechanical efficiency was significantly lower for the older than for the younger subjects.

Mechanical efficiency decreased from about 23 to 11 per cent when decreasing the work load from 450 to 50 kpm/min.

The consequences of these findings are discussed in relation to the reliability of work tests.

PART III, VITAL CAPACITY AND 1.0-SECOND'S EXPIRATORY CAPACITY IN WOMEN 20—65 YEARS OLD. p. 33—34.

Fast vital capacity (FVC) and 1.0-second's expiratory capacity (1.0-sec EC) were measured in 44 physically active female subjects, 20—65 years old.

FVC decreased from 3.79 for the 20—29-year-old group to 3.24 l for the 50—65-year-old group. 1.0-sec EC decreased from 84.3 per cent of FVC to 79.3 per cent for the corresponding groups. These findings agree with earlier investigations in this field.

PART IV, ELECTROCARDIOGRAMS AT REST AND DURING AND AFTER WORK IN WOMEN 20—65 YEARS OLD. p. 35—44.

Electrocardiograms were recorded at rest, during and after work, at loads ranging from low to maximal, on a bicycle ergometer for 44 physically active female subjects 20—65 years old.

Two subjects had a suspected pathological "rest" ECG, probably depending upon a so-called sympathicotonic reaction.

The occurrence of suspected pathological and pathological "work" ECG increased with increasing age, and with increasing work loads. Seven out of eleven "work" ECGs in groups 3—4 were recorded during the two highest work loads.

Only four of these eleven subjects would have had a diagnosis in groups 3—4 if the recordings had been made only after the work. The validity of these findings is discussed.

PART V, A METHOD FOR PREDICTION OF AEROBIC WORK CAPACITY FOR FEMALES AND MALES OF DIFFERENT AGES. p. 45—60.

A nomogram for prediction of the aerobic work capacity from submaximal tests on a bicycle ergometer, a treadmill or from a step test was earlier constructed for subjects 18—30 years old. This nomogram was now *adjusted for lower loads and a correction factor for both females and males in older ages was introduced.*

The material used for this last-mentioned calculation consists of 76 females and 129 males, 20—68 years old. In all subjects oxygen uptake and heart rate was measured at submaximal and maximal loads on a bicycle ergometer.

The prediction from relatively low and high work loads with regard to accuracy, the error of the method and the testing procedure are discussed.

PART VI, A PILOT STUDY OF WORK ON A TREADMILL IN WOMEN 20—65 YEARS OLD. p. 61—63.

Forty-two physically active female subjects 20—65 years old walked on a treadmill with a fixed speed of 5 km/hr. The oxygen uptake during work agrees with earlier results. The influence of the body weight for the oxygen uptake when walking is discussed. *Different test methods are compared.*

PART VII, PHYSIOLOGICAL EFFECTS OF PROLONGED MUSCULAR WORK FOR ONE HOUR AND FOR ONE DAY. p. 64—73.

The hypothesis of "the 50 per cent load" as the upper limit for daily work was taken up for investigation in 18 female subjects 40—65 years old and in 2 female and 2 male younger subjects. The subjects worked continuously for 1 and 7 hours, respectively, on a treadmill or a bicycle ergometer, with a load corresponding to 50 per cent of their aerobic work capacities.

All performed work for one hour without any increase after about the 5th min in pulmonary ventilation, oxygen uptake, heart rate or blood lactate concentration.

During the seven hours' period, the subjects showed an increasing oxygen uptake, pulmonary ventilation and heart rate. These findings indicate that "the 50 per cent load" should probably not be exceeded when working for a whole day.

The reasons for the increase in oxygen uptake and heart rate are discussed with regard to a successive transfer to fat combustion and with regard to dehydration. It was assumed that the body temperature during work adjusts itself according to the *relative* load on the subjects and not to the absolute.

GENERAL DISCUSSION

The human body consists of muscles to about forty per cent. At rest this large portion of the total body mass has a relatively low metabolic rate and is responsible only for some twenty per cent of the resting oxygen uptake. No other tissue of the body has, however, the same capacity to increase its metabolic rate. The aerobic metabolism of this tissue, expressed as oxygen uptake, may increase more than one hundred times, and through anaerobic processes an increase of several hundred times is possible. For this reason it is understandable that the transition from rest to work may involve radical changes in the muscle tissue and of the whole organism. The higher the relative work load is, the more difficult it will be for the different regulating mechanisms of the body to maintain the normal state of equilibrium or to restore a disturbed equilibrium.

"Fitness, apparently, consists in the ability of the organism to maintain the various internal equilibria as closely as possible, to the resting state during strenuous exertion and to restore promptly after exercise any equilibriums which have been disturbed" (DARLING, 1947).

Capacity, or fitness, for a certain work is also closely interrelated with fatigue, if fatigue is looked upon as a state of "disturbed equilibrium". According to BARTLETT's definition (1953, p. 1): "Fatigue is a term used to cover all those determinable changes in expression of an activity which can be traced to the continuing exercise of that activity, under its normal operational conditions and which can be shown to lead, either immediately or after delay, to deterioration in the expression of that activity".

According to DILL (1936): "The factor of safety may be defined as the ratio of the maximal increment in oxygen transport to the observed increment in oxygen transport."

For maintaining a normal equilibrium in the different tissues under varying conditions an adequate blood supply will always be the most important prerequisite. The type of fitness which is necessary for prolonged muscular exercise is well correlated to the individual's oxygen uptake capacity (for ref. see P.-O. ÅSTRAND, 1956). The pulse rate during work (KJELLBERG, RUDHE and SJÖSTRAND, 1949; SJÖSTRAND, 1956) and the maximal $\dot{V}o_2$ (P.-O. ÅSTRAND, 1952, p. 48) are highly correlated with the total amount of hemoglobin and the blood volume. The capacity of the circulatory organs is probably developed in proportion to the size of skeletal muscles. The aerobic work capacity is, namely, also well correlated with the lean body mass (weight — adipose tissue)$^{2/3}$, see v. DÖBELN, 1956 a, p. 49 ff. The same author showed (1956 b) that the correlation coefficients between maximal oxygen uptake on one hand and total amount of hemoglobin or (weight — adipose tissue)$^{2/3}$, on the other were not

significantly different from each other. Maximal oxygen uptake is highly correlated with body weight in children and young adults without excessive amount of fat (P.-O. ÅSTRAND, 1952, p. 106). The same holds true for maximal oxygen uptake in relation to body height. (ASMUSSEN and HEEBØLL-NIELSEN, 1955). These different parameters have accordingly been studied for many years, and we know their relationships to each other, at least in younger individuals. If some of the relationships are different in older people we do not know. However, the aerobic work capacity or the oxygen uptake capacity decreases with increasing age and thereby also the fitness as defined here. Therefore, an average older person becomes more fatigued at a certain work load, and the factor of safety must be considered in relation to the decrease in aerobic work capacity.

Aerobic work capacity — physical fitness

AGE

In the present investigation a decrease in the aerobic work capacity with increasing age was found (I. ÅSTRAND, 1958 a; part I, p. 23). For female subjects it decreased from 2.23 to 1.85 l/min, or with 17 per cent, (28 per cent when calculated per kg body weight) from about 25 to 55 years of age (part I, p. 16); for male subjects it decreased from 3.01 to 2.23 l/min, or with 26 per cent (21 per cent per kg body weight) from about 35 to 63 years of age (part V, p. 48). ROBINSON (1938) found a decrease from 3.53 to 2.63 l/min, or of about 25 per cent, (21 per cent per kg body weight) for males from about 25 to 50 years of age. The decrease was 30 per cent from about 35 to 63 years of age (3.42 to 2.35 l/min) (20 per cent when calculated per kg body weight). Similar changes of other biological functions are reported in literature. Thus, the muscular force displayed by the biceps decreases with about 32 per cent from 25 to 55 years of age, and the force displayed by the back muscles with about 28 per cent (UFLAND, 1933). Concerning the lung function, it may be mentioned that both the vital capacity, 1.0-sec expiratory capacity and the diffusing capacity decreases, while the residual volume increases. COWDRY, 1952, discusses in detail how the functions of the various organs change; concerning ageing and the psychical functions, the reader is referred to WELFORD, 1958.

The general trend of the various organs is a decrease in functional capacity with increasing age when averages for different age groups are compared. However, the standard deviation of the values are usually considered to be much greater in the older group than in the younger. Many older persons are just as capable as an average young person. Several examples of this are found in the present material. A 57-year-old female reached a maximal oxygen uptake of 2.33 l/min, which was fifth best of 44 females 20—65 years old. The question is whether or not the older group consists partly of individuals

who have aged relatively much and partly of individuals who have aged comparatively little, or to what extent the chronological and the biological age correspond to each other. One should be careful in drawing conclusions from average values before this question has been answered. When selecting individuals for certain jobs or vice versa, it is certainly very important to test the capacity of the individual.

However, average values are valuable when one wishes to obtain a general idea about the influence of ageing on a certain function. For such evaluations, it is of course important to have comparable materials of younger and older individuals as far as physical training is concerned. In the present material this requirement has partly been met with, since all subjects compared were physically active either by participating in organized calisthenics or by having a relatively heavy job. Older persons who have kept a relatively heavy job may, however, comprise a selected group, and their capacities may be relatively too high as compared to younger persons. In the present material, the draymen (I. ÅSTRAND, 1958 a) may comprise such a group.

In the female material (part I, p. 11) a selection such as that mentioned above has certainly occurred to a considerably less degree. On the other hand, persons who participate in organized calisthenics have a certain aptitude and talent for physical activity and comprise a selection in this respect. It was from such a group that the material for this study was recruited. The severity of the calisthenics which is performed in such associations is, however, comparatively low and will probably not prevent too many "healthy" 60—70-year-olds from participating. Experience has shown that resignation from these associations is not greater among the older than among the younger persons. In this connection, it is important to point out that regardless of how the selection is made for an investigation of this type, the material will never be wholly unchallengeable.

Independently of how well the present material fills the requirements for comparability between younger and older persons it is, however, of great interest to note that the oldest males reached exactly the same average maximal oxygen uptake as the youngest females when cycling.

We do not know with certainty what factor is the most limiting for the aerobic work capacity in younger persons. For discussions see SJÖSTRAND, 1953 and P.-O. ÅSTRAND, 1956. With increasing age the functions of the various organs change with differing speeds in different individuals. It is probable that this holds true also for the functions of the different organs which are involved in the aerobic work capacity. Therefore, it might be rather meaningless to search for detailed reasons which should be common for all individuals for the decrease in aerobic work capacity. It is probable that this is limited in different ways for different individuals.

However, it may be pointed out that the decrease in aerobic work capacity is noted together with a decrease in the average maximal heart rate which is

TABLE I. *Mean values ± standard errors of the means for oxygen pulse at submaximal and maximal loads for the different age groups in the female material (part I)*

age group, yr.	n	oxygen uptake, l/min			
		0.91 ± 0.01	1.19 ± 0.01	1.51 ± 0.01	max.
20–29	8	7.4 ± 0.41	8.7 ± 0.38	9.9 ± 0.37	11.9 ± 0.45
30–39	12	7.8 ± 0.31	8.7 ± 0.99	9.7 ± 0.30	11.5 ± 0.47
40–49	8	7.6 ± 0.36	8.7 ± 0.33	9.7 ± 0.49	11.4 ± 0.46
50–65	16	8.6 ± 0.28	9.5 ± 0.37	10.3 ± 0.36	10.9 ± 0.42

attainable during the type of work performed. Actually this decrease begins already at childhood, cf. P.-O. ÅSTRAND, 1952, p. 29. "The etiology of the decrease in maximal heart rate with age is still obscure. Contrary to the case of subjects partly acclimatized to hypoxia (P.-O. ÅSTRAND and I. ÅSTRAND, 1958), the substitution of oxygen for room air as the inspired gas did not significantly change the maximal heart rate in the 56—68-year-old subjects." This quotation is taken from I. ÅSTRAND, P.-O. ÅSTRAND and RODAHL (1959).

In the female material the degree of physical training is judged to be similar in the different age groups (part I, p. 11). The oxygen pulse is of the same size for the 20—29, 30—39, and 40—49-year-old groups at both submaximal and maximal loads, see Table I. However, the values of the 50—65-year-old group deviate from the three others. At the submaximal loads the oxygen pulse is relatively high and at the maximal loads about equal when consideration is paid to differences in body size. It is impossible to state whether or not these deviations depend upon a different size of the stroke volume and/or arterio-venous oxygen difference for the oldest group as compared with the three other groups. Before this question can be answered a determination of the cardiac output during maximal work should be made. Regarding the regulation of cardiac output during work the reader is referred to ASMUSSEN and NIELSEN (1955).

PHYSICAL TRAINING

The aerobic work capacity does not only vary with age but also, among other things, with physical training or lack of training, and work environment. Up till now, exact measurements of the physiological effect of physical training have been made mostly on athletes and younger persons (for ref. see P.-O. ÅSTRAND, 1956). In the last few years, however, one has become more and more conscious of the great importance of a good physical condition, especially for older persons, patients and convalescents. An interesting study on the effect of organized physical training for patients with a low work capacity was made by HOLMGREN *et al.* (1957; 1959 a). In this field, more basic research is essential concerning the effect of various training methods with regard to

TABLE II. *Evaluation of the aerobic work capacity in the various age groups for females and males. The aerobic work capacity, $\dot{V}O_2$ ml/kg, was calculated with a "normal" body weight chosen as 58 and 72 kg for females and males respectively. These figures for weight were taken from Spector (1956 p. 180) and represent the averages for a white woman and man between 25 and 35 years of age*

age group, yr.	aerobic work capacity, $\dot{V}O_2$, l; ml/kg				
	low	fair	average	good	high
♀ 20–29	< 1.69	1.70 – 1.99	2.00 – 2.49	2.50 – 2.79	2.80 >
	< 28	29 – 34	35 – 43	44 – 48	49 >
30–39	< 1.59	1.60 – 1.89	1.90 – 2.39	2.40 – 2.69	2.70 >
	< 27	28 – 33	34 – 41	42 – 47	48 >
40–49	< 1.49	1.50 – 1.79	1.80 – 2.29	2.30 – 2.59	2.60 >
	< 25	26 – 31	32 – 40	41 – 45	46 >
50–65	< 1.29	1.30 – 1.59	1.60 – 2.09	2.10 – 2.39	2.40 >
	< 21	22 – 28	29 – 36	37 – 41	42 >
♂ 20–29	< 2.79	2.80 – 3.09	3.10 – 3.69	3.70 – 3.99	4.00 >
	< 38	39 – 43	44 – 51	52 – 56	57 >
30–39	< 2.49	2.50 – 2.79	2.80 – 3.39	3.40 – 3.69	3.70 >
	< 34	35 – 39	40 – 47	48 – 51	52 >
40–49	< 2.19	2.20 – 2.49	2.50 – 3.09	3.10 – 3.39	3.40 >
	< 30	31 – 35	36 – 43	44 – 47	48 >
50–59	< 1.89	1.90 – 2.19	2.20 – 2.79	2.80 – 3.09	3.10 >
	< 25	26 – 31	32 – 39	40 – 43	44 >
60–69	< 1.59	1.60 – 1.89	1.90 – 2.49	2.50 – 2.79	2.80 >
	< 21	22 – 26	27 – 35	36 – 39	40 >

work load, duration and frequency of repetition on older as compared to younger persons and on various categories of patients. Physical training should aim at optimal effect with the least possible strain. This optimum is probably different for different categories and ought to be adjusted, for example, according to the job requirements.

Classification of aerobic work capacity

The individual variation in the circulatory response both to submaximal and maximal work is very large even within a relatively homogeneous group of "healthy" persons, see part I, p. 25. This variation is certainly even more pronounced in a so-called "normal population" including well-trained athletes on one side and convalescents and persons without a well established state of health on the other. This means that it is very difficult to define the range within which the aerobic capacity should fall in order to be considered as normal, high, etc. On the other hand, it is desirable to have certain norms to follow when judging a person's work capacity. However, it should be emphasized that a person's capacity should always be related to his profession, occu-

pation, etc. A person with a low aerobic work capacity in relation to the average may be "normal" in relation to the demands of his job. The variability of the aerobic work capacity of an individual makes a judgment still more complicated. An individual's measured or predicted capacity should therefore also be related to his state of health and degree of physical training. Sometimes it is more essential to follow the physical status of a person or a patient for a longer period or to classify an individual for a well defined physical demand instead of classifying him in relation to the average.

An attempt has been made in Table II to make such a classification even though this must always involve certain defects. The levelled off values from Table V: II were used when composing the table. Approximate mean values $\pm$ 1 $\times$ S.D. were set as the limits for an average aerobic work capacity for the two sexes and the different ages. For the other classifications approximately 1 $\times$ S.D. was used as the limit. One very important pre-requisite that these values may be considered average, high, etc. is that *body size is "normal"*. Similar values for the aerobic work capacity divided by a "normal" body weight are included in the table.

When estimating the aerobic work capacity (as described in part V) of the 39 subjects presented by GEMZELL, ROBBE and STRÖM (1957) and ROBBE (1958) one arrives at an average value of about 2.1 l/min. These subjects were healthy young women and their capacity will be classified as "average" according to the table. With the same method applied the capacities of the 58 women and 67 men presented by FRISK *et al.* (1957) will be classified as "average" and "fair" respectively and that of the male material of HOLMGREN and STRANDELL (1959) as "average". These classifications seem to be reasonable and therefore they support the general construction of this table.

Safety margin for daily work

PLACEMENT OF OLDER WORKERS

The above-mentioned facts about variations in the aerobic work capacity and the requirements for a certain safety margin have extensive consequences when making a placement or replacement, especially of older workers. However, it is important that an evaluation is not made only from the older individual's aerobic work capacity at a replacement from a heavy job. His greater experience and better technique obtained through the years may compensate for his lowered capacity. By introducing rest pauses of a certain duration in relation to the work time, one can often modify the physiological strain of a given work load so that it becomes tolerable even for older persons (cf. CHRISTENSEN, HEDMAN and HOLMDAHL, 1960; I. ÅSTRAND *et al.*, 1960 a and b). In this way, replacement can often be avoided. The draymen's job is a typical example of this (I. ÅSTRAND, 1958 a). The reason why older persons can perform this

TABLE III. *Mean values ± errors of the means and S. D. of heart rate for the two sexes and the various age groups when using 50 per cent of the aerobic work capacity*

age group, yr.	n	females	n	males
[1] ♀ 20–25	32	138 ± 2.2	29	127 ± 1.6
[1] ♂ 20–33		8.8		8.3
20–29	8	132 ± 5.1	4	124
		14.5		
30–39	12	129 ± 3.6	13	116 ± 2.1
		12.3		7.4
40–49	8	127 ± 4.2	9	113 ± 3.5
		11.9		10.6
50–59			66	98 ± 1.9
				15.0
	16	108 ± 3.3		
		13.1		
60–69			8	92 ± 5.4
				15.3

[1] Physical education students from P.-O. Åstrand's material of 1952.

job is because they can choose their rest periods when best needed. Further examples of this may be found in forest work.

"THE 50 PER CENT-LOAD"

"Machines are not usually run at more than 50 per cent of their capacity, and a similar safety margin should perhaps be allowed to man and animals so as to avoid injury or untimely death" (BRODY, 1945, p. 906). This hypothesis has been tested in the present investigation. Older and younger subjects performed continual work on the bicycle ergometer or treadmill for 1 hour or for 7 hours at a load which required 50 per cent of their aerobic work capacities (I. ÅSTRAND, P.-O. ÅSTRAND and RODAHL, 1959; part VI—VII, p. 62). From the results it may be pointed out that the 50 per cent level should probably be considered as the upper limit, at least with work periods of longer duration than one hour.

" 'The 50 per cent load' must be related to the capacity of the muscles involved and not to that of the body as a whole" (P.-O. ÅSTRAND, 1952, p. 148). In most types of professional jobs where it is desirable to appraise the individual's aerobic work capacity, both the trunk, arm and leg muscles are engaged. Cycling on the ergometer, walking or running on the treadmill, or the step test, which engage large muscle groups, may therefore be considered suitable aids in determining the aerobic work capacity (RYHMING, 1953; P.-O. ÅSTRAND and RYHMING, 1954; part V, p. 45). These work forms are also

suitable to use in health examinations, if the aim is to include an evaluation of the aerobic work capacity and an appraisement of the functions of the circulatory and respiratory organs.

Practically, no person with an aerobic capacity of less than 2 l/min should perform a continual work which requires an oxygen intake of 1 l, if one accepts "the 50 per cent load". If one wishes to be certain not to overestimate more than a few persons one must, when predicting the aerobic work capacity, consider not only the actual figures but also the error of estimation, (see part V, p. 56). The critical limit for each individual during the actual work can be easily obtained from individual curves on the heart rate and oxygen uptake or work load. One pre-requisite is that the variation in maximal heart rate is taken into consideration. The average values for heart rate when using 50 per cent of the aerobic work capacity, for the present material (part V) of 205 subjects, are given in Table III.

It is evident that under certain conditions one can accept a work load which demands more than 50 per cent of the individual's aerobic work capacity. One pre-requisite is that the work consists of peak loads of a short duration and in between is of low intensity. Regarding the energy expenditure during various industrial and domestic activities see PASSMORE and DURNIN, 1955.

MOVING OF THE BODY WEIGHT

If a work involves moving of the body, a greater body weight means a greater load on the organism. When walking at a speed of 5 km/hr, a weight of 65 kg means an oxygen uptake which is about 0.15 l/min greater (17 per cent) than for a 55 kg subject (see part VI, p. 62). A measure which is related to the body size ought to be used when recommending a worker for a job where he must move his body weight. If one has determined that a person ought to have an oxygen uptake capacity of 3.0 l/min, this means 40 ml/kg $\times$ min for a person weighing 75 kg. However, for a person weighing 85 kg, 40 ml/kg $\times$ min means a total oxygen uptake of 3.4 l/min. Both the total and the relative work capacities should be of sufficient sizes.

EFFECT OF ADDITIONAL FACTORS

When working in a hot climate an increased blood flow through the skin will be necessary for heat elimination. At a certain oxygen uptake an extra load will be placed on the blood circulation. The heart rate will increase out of proportion to the work load or oxygen uptake (DILL *et al.* 1931; CHRISTENSEN, 1953, p. 105). Consideration must be given to this extra load when judging man's capacity to perform work in such an environment. For heat regulation see ROBINSON (1949, p. 109 ff).

A standing, and even a sitting, position involves unfavourable distribution of the blood to the lower part of the body depending upon the hydrostatic conditions, cf. for instance LAGERLÖF *et al.* (1951). Even when performing

work this hydrostatic factor will result in a higher heart rate and smaller stroke volume in standing and sitting as compared to recumbent position (ASMUSSEN, CHRISTENSEN and NIELSEN, 1939 a and b; ASMUSSEN and CHRISTENSEN, 1939). LUNDGREN (1946, p. 95 ff) showed that in forest workers a heart rate increase during the work day could partly be reduced by bandaging the legs. Consequently, consideration ought also to be given to the working posture when evaluating man's capacity to perform work.

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